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V AND ICE REMOVAL FROM PAVEMENTS G STORED EARTH ENERGY

W. B. Bienert, et al.

May 1974

Final Report

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16. Abstract

The technical feasibility of using earth heat in combination with heat pipes for deicing and removing snow from pavement surfaces has been demonstrated (in the Baltimore/Washington climate) in testing conducted at the Fairbank Highway Research Station (located at McLean, Virginia) during two Winters. This report describes the analytical models constructed to describe earth heated pavement systems, and the validation of these models as a result of the testing conducted. A highway engineer's user section is included in this report which provides step-by-step examples of how pavement heating systems may be defined and specified. The user section also describes step-by-step procedures for defining electrically heated pavements. Problems encountered during the construction of the Fairbank test site are discussed and related to potential problems foreseen in field installations. Cost estimates as a function of various climates for earth heated pavement systems are also presented.

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UNITED STATES GOVERNMENT
Memorandum

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
Washington, D.C. 20590

DATE: March 18, 1975

In reply refer to: HHO-31

SUBJECT: Transmittal of Research Report No. FHWA-RD-75-6, "Snow and Ice Removal From Pavements Using Stored Earth Energy"

FROM : Director, Office of Research
Director, Office of Highway Operations

TO : Regional Federal Highway Administrators
Region 1, 3-10

This memorandum distributes the subject report, which has significant potential for use in the development of experimental projects. The report will be of interest to researchers, designers, and maintenance personnel concerned with snow and ice removal from pavements.

The analysis in this report demonstrates the feasibility of using earth heat transported by heat pipes to the pavement for deicing roadways. The earth heat pipe system is passive - it only uses the "free" energy stored in the earth. A full-scale research installation described in the report has demonstrated the validity of this concept. Since the installation was not on a highway and thus, not subjected to highway conditions, experimental projects are encouraged under the following conditions:

1. The site should be at a location that usually experiences a moderately severe winter.

2. The site should be an interchange ramp where the State feels there is a winter maintenance problem, such as a steep grade on a ramp or a location that is difficult to include in a normal plowing route. The site should not be an elevated section.

3. The ramp should be constructed of portland cement concrete and should either be scheduled for a portland cement concrete overlay in the near future or the State should be willing to remove a section of the ramp in order to install an experimental section. It also may be new construction.

4. It is suggested that the location be in close proximity to a State highway office where personnel are located who can monitor the site throughout the winter.

5. There should be power available for any monitoring equipment, such as a series of thermocouples or a video tape unit, etc. The system itself needs no power.

6. The State must be willing to assign personnel qualified to evaluate the system on a technical basis and must be willing to control or even stop winter maintenance at the site or keep accurate records of the amount of maintenance performed (tons of salt, number of applications, etc.).

7. Projects approved under these criteria will be classified Category 1 under the requirements of the Federal-Aid Highway Program Manual, Volume 6, Chapter 4, Section 2, Subsection 4, Construction Projects Incorporating Experimental Features.

The importance of experimental construction utilizing a pavement heating concept, such as is evolving from this research, cannot be overemphasized. The initial cost of conventional heating systems utilizing external energy sources can be quite large, and the annual energy charge for operating the system, where no Federal assistance is involved, is a heavy burden and, in some cases, greatly exceeds costs of maintaining special winter maintenance crews solely for snow removal of the facility itself. We urge you to encourage trial installations of the earth heat system in an experimental project in your region.

Distributed with this memorandum are sufficient copies of the report to provide a minimum of one copy to each regional office, one copy to each division office, and one copy to each State highway agency. Direct distribution is being made to the division offices. Additional copies for official use may be requested from Mr. David Solomon, Chief, Environmental Design and Control Division, FHWA HRS-41, Washington, D.C. 20590. These requests will be filled while our limited supply lasts. Additional copies for the public are available from the National Technical Information Service, Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22151. There is a small charge for each copy ordered from NTIS.

Ross W. Kruser

Ross W. Kruser

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Attachments

ACKNOWLEDGEMENTS

The authors acknowledge the encouragement and valuable assistance given during the course of this program by Federal Highway Administration, Department of Transportation technical personnel. Specifically, appreciation is extended to G. Bennett (retired), R. Schwab, M. Freitas, and P. Brinkman. Further, the initial efforts of P. Marjon are hereby acknowledged.

Many persons and organizations made valuable contributions during the course of this program. Special appreciation is extended to Corson & Gruman Co., Inc., for the test site construction and to G. Edgar Harr Sons' Corp. for drilling of the holes for the earth heat pipes. The contributions of Dr. Robert L. Kondner in pavement design and soil mechanics are acknowledged.

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I INTRODUCTION

A. Background

During the past 25 years, various pavement snow removal and deicing systems have been studied and a number have been built and tested. A variety of energy sources have been considered. These include electrical, fossile, decay heat from fission products, solar, and the heat from the earth. Dynatherm Corporation under contract to the Department of Transportation, Federal Highway Administration, has studied the feasibility of using the decay heat from fission products for removing snow from and deicing of roadway surfaces (Reference 8). The economics of this system were compared with that of systems utilizing other heat sources. It was concluded that, because of the limited availability of fission product energy and because of the safety problems associated with utilizing this energy form, a wide application of this system was not possible.

Of the other energy sources studied, a snow removal and deicing system utilizing the stored energy in the earth beneath and adjacent to the roadway pavement appeared to be technically feasible and furthermore had the least impact on the Nation's energy requirements. Simultaneously, it was recognized that the economics of such a system were critically dependent upon the volume of earth that had to be thermally coupled to each square foot of the pavement surface. This volume of earth, in turn, is dependent upon the efficiency of transporting and distributing the earth's thermal energy, the average temperature of the earth (related to the average annual environmental temperature), the nature and composition of the soil, the conductivity of the pavement, and on the total annual energy required to remove snow and deice pavement surfaces.

The "heat pipe" (Reference 12), a relatively new space age development, was selected to transport the thermal energy from the earth to the pavement. The heat pipe is

a vacuum tight structure, evacuated of all noncondensible gases, containing a capillary wick along its internal length, and within which a small amount of vaporizable heat transfer fluid has been introduced. The capillary wick acts like a small pump to pump the condensed Vapors (fluid) from areas where heat is extracted from the system to areas where heat is added to the system. In areas where heat is added to the system the fluid is vaporized and the cycle is repeated. Because heat energy is transported by vapor, the heat pipe can be relatively small in diameter. Furthermore, since the heat transfer process is one of evaporation and condensation (a constant temperature process), the heat pipe is an isothermal device. This is an important characteristic in low temperature earth type heated systems.

B. Statement of Problem

The ability to deice and remove snow by heating pavements is well established, and electrical heating elements are commercially available for this purpose (Reference 3). Empirical methods exist which can be used to specify the pavement heating requirements (watts/ft^2) for any given set of ambient conditions. These methods yield very conservative estimates for the heating requirements and, furthermore, do not account for system transient behavior. Since the installation and operating costs associated with a pavement heating system are determined by the heating requirements, validated analytical techniques must be available to highway engineers so that the most economical pavement heating system can be specified.

Electrical heat sources supply constant power whereas earth heat sources are at a constant temperature. The power supplied to a heated pavement from an electrical heat source is constant irrespective of the ambient conditions. The power supplied to a heated pavement from an earth heat source is not constant but is related, in a rather

complex way, to the temperature difference between the pavement surface and the bulk earth temperature. The pavement surface temperature is determined by the ambient history and present ambient conditions. Because the earth temperature is low ($\sim 55^{\circ}F$ in moderate climates), thermal resistances between the earth and the heat pipe and between the heat pipe and the pavement surface are of critical importance. These sistances must be determined experimentally.

C. Program - Objectives and Outline

Phase I of this program resulted in the recommendation to further study earth heat in combination with heat pipes for pavement deicing and snow removal (Reference 8). The following objectives were then set forth for the Phase II portion of the program:

- Develop analytical tools to predict the deicing and snow removal capabilities of heated pavements using earth as the heat source and heat pipes as the heat transport devices.

- Design and construct a test facility at Fairbank Highway Research Station to demonstrate the deicing and snow melting capabilities of earth heat pipe pavement heated systems.

- Include in the test facility the ability to relate heating requirements to snow melting capability.

- Obtain test information from the test facility to validate the analytical tools and obtain experimental information.

- Develop and present an analysis approach which may be followed by State highway engineers to specify pavement heating systems.

The analytical work proceeded and is summarized in Section II, Analytical Modeling and Predicted System Behavior. The computer programs are summarized in Appendix A. This work highlighted several areas where information was either unavailable or unreliable.

- The short-term thermal resistance (^{o}F/watt-ft^{2}) between the heat pipe and the bulk ground was unavailable. Reference 22 quoted resistances as a function of time of heat extraction in days. Taking the maximum value quoted by Ingersoll for a single isolated heat pipe yielded a resistance of 0.0327 ^{o}F/watt for a 40-foot long pipe. The experimental value, averaged over a few hours of melting load, (page VI-12 of this report) is, by comparison, 0.081 ^{o}F/watt.

- Accurate values of the thermal conductivity of Class AA PPC concrete used in highway pavements were unavailable from literature or from the U. S. Bureau of Standards.

- The value of thermal resistance between the heat pipe and the concrete pavement surface was unavailable.

- The ability of the earth to recover heat extracted by the heat pipes was unknown. Earth recovery had been measured in connection with heat pump applications for conditions different than those proposed for this application (Reference 22).

In order to proceed with the design of the test facility at a minimum risk, small scale testing was initiated. This testing is described in Section III, Component Testing and Results. Basically, testing was conducted in three general areas:

- Feasibility Testing: Typically, these tests consisted of electrically heated heat pipe concrete slabs and single earth-embedded heat pipes.

- Design Testing: In this catagory, methods of thermocouple attachment were explored, iron-ammonia compatibility testing was conducted, methods of diffusing heat in concrete were explored, and various mechanical details were checked out.

- Innovative Testing: Several technical areas were explored which, if successful, would result in significant improvements in system economics and which could be incorporated in the testing at Fairbank Highway Research Station. The two most significant areas investigated were shutoff valves on each pipe to conserve energy and down-pumping heat pipes which would utilize the pavement as a solar collector and pump this heat down into the earth.

Of the above areas of testing, all programmed tests were successfully completed except those of the innovative type. In this catagory, the testing was terminated in order that funds would be available for additional winters testing at Fairbank Highway Research Station.

A description of the Fairbank Highway Research Station test facility and its construction is given in Section IV. A description of the testing conducted during two Winter seasons is also presented in this section. Basically, the test facility consists of three highly instrumented concrete test slabs. The slabs were constructed in accordance with standard highway specifications (Reference 7). The three slabs and their test purposes are given below:

- Electrically Heated Slab: Constructed for the purpose of relating heating requirements to snow melting capability.

- Earth Heated Slab: Constructed for the purpose of demonstrating concept feasibility and obtaining necessary technical data.

- Control Slab: Constructed to enable factoring-out of test data extraneous enviornmental variables.

During the first Winter, simulated testing was conducted using flake ice since mother nature did not cooperate and provide a natural snow enviornment. During the second Winter, both natural snow and flake ice testing was conducted. The analysis of the test data is presented in Section V.

Several anomalies occurred during testing and made data analysis difficult. The most significant of these was conserned with the generation of noncondensible gases in the earth heat pipes. In all cases, computational techniques were evolved which permitted the analysis to proceed.

The culmination of the analytical effort permitted the preparation of Section VI, Highway Engineer's User Data. The scope of the program did not permit the compilation of the data in table form.

II. ANALYTICAL MODELING AND PREDICTED SYSTEM BEHAVIOR

A. Determination of Thermal Losses as a Function of Climate

In order to predict the behavior of a concrete surface subjected to its transient natural environment, the thermal losses must be defined as a function of the ambient conditions. The modes of heat transport at the concrete surface are convection, radiation, and, in the case of a wet surface, evaporation. Empirical equations are available which relate these losses to ambient temperature (T_a), wind velocity (v), cloud cover (n), and vapor pressure (e).

Convective heat transfer at the surface is defined in Reference 1 by the equation,

$$q_{cv} = (1 + .3\, v)\,(T_s - T_a)/3.41 \qquad \text{II-1}$$

where:

q_{cv} = convection heat loss (watts/ft^2)

T_s = temperature of surface (^oF)

v = wind speed (mph)

The radiation loss to the ambient can be expressed as the difference between the heat radiated by the surface and the incident long wave radiation. Using Kirchhoff's Law to express the radiative heat flow between a black and a gray surface (assuming the black body sink temperature is 10^oF lower than the ambient temperature), the following equation is obtained (Reference 1):

$$q_r = \left[\varepsilon \sigma T_s^4 - \varepsilon\sigma (T_a - 10)^4\right](1 - 0.75\, n) \qquad \text{II-2}$$

where:

ϵ = emissivity of concrete (taken as 0.9)

n = cloud cover in tenths

Another equation, given by Raman (Reference 2), defines the radiation heat loss as a function of the vapor pressure, since long-wave radiation originates chiefly from water vapor and carbon dioxide. Raman's equation is,

$$q_r = \left[\varepsilon \sigma T_s^4 - \varepsilon \sigma T_a^4 \left(0.77 - 0.28 \left(10^{-0.074 e}\right)\right) \right] (1 - a\, n) \qquad \text{II-3}$$

where: e = vapor pressure in mm of Hg

a = numerical constant dependent on cloud height (0.87 - 0.45)

These equations result in substantially different radiation losses; however, for small surface-ambient temperature differences, both can be approximated by straight line relationships with the same slope but different constants c:

$$q_r = (.22\,(T_s - T_a) + c)\,(1 - .75\, n) \qquad \text{II-4}$$

From experimental results (see Section V), it was found that a value of 3.50 for the constant c best satisfies the heat balance on the concrete slab. The resulting radiation loss is bordered by the two referenced empirical relationships. Thus, the equation used in our mathematical model in watts/ft^2 is:

$$q_r = (0.22\,(T_s - T_a) + 3.50)\,(1 - .75\, n) \qquad \text{II-5}$$

For a wet surface, evaporation introduces another thermal loss to the ambient. The evaporative heat loss is written as (Ref. 3):

$$q_e = (0.0201\, v + 0.055)\,(p_{vw} - p_{va})\, h_{f,g}/(3.41) \qquad \text{II-6}$$

where: q_e = evaporative heat loss (watts/ft^2)

p_{vw} = vapor pressure associated with surface temperature (inches of Hg)

p_{va} = atmospheric vapor pressure (inches of Hg)

$h_{f,g}$ = enthalpy of saturated vapor at surface temperature (Btu/lbm)

It is assumed that the radiative and convective heat losses are unchanged for a wet surface.

These equations completely define the thermal losses to ambient as a function of climatic conditions and the surface temperature of the concrete. However, when the concrete surface is covered by a layer of snow or ice, the losses are determined by the temperature at the surface of the covering. This surface temperature is not only a function of the ambient conditions but also of the conductive properties and thickness of the surface covering. This temperature is uniquely defined by the following equations:

$$q_{loss} = f(T_s, T_a, v, n, e) \qquad \text{II-7}$$

$$q_{loss} = k_{sc} \frac{T_c - T_s}{\text{thickness of covering}} \qquad \text{II-8}$$

where:

T_c = concrete surface temperature

T_s = cover's surface temperature

k_{sc} = thermal conductivity of surface covering

Combining Equations II-7 and II-8 yields the surface temperature of the covering, and the losses may then be determined from either equation.

B. Annual Thermal Losses as a Function of Climate

Once the thermal losses have been defined as a function of ambient conditions and the surface temperature of the concrete, the annual thermal losses can be obtained

by integrating typical annual weather information. The following data were obtained on a monthly basis from the U. S. Weather Bureau for Baltimore, Maryland, and Syracuse, New York:

- Average Daily Temperature
- Average Wind Velocity
- Average Cloud Cover

These cities were selected because they respectively represent moderate and severe climates and because weather data are available.

Since the average daily temperature was used, it was assumed that the period of dissipation was 24 hours on those days when the average ambient temperature was lower than the surface temperature of the concrete. The heat balance governing the energy dissipation from the concrete surface is:

$$\dot{q}_{dis} = \dot{q}_r + \dot{q}_{cv} - \dot{q}_{sol} \qquad \text{II-9}$$

where:

$\dot{q}_{dis}$ = net heat dissipated from dry concrete

$\dot{q}_r$ = heat loss by radiation to ambient

$\dot{q}_{cv}$ = heat loss by convection

$\dot{q}_{sol}$ = solar heat absorbed by dry concrete

In dealing with the solar radiation term of the heat balance, the Savino-Angstrom formula (Reference 4) has been used.

$$\dot{Q}_{sol} = (Q + q)_o \left[1 - (1 - \lambda)\, n \right] \qquad \text{II-10}$$

where:

$(Q + q)_o$ = total radiation with cloudless sky

λ = coefficient depending upon latitude

n = degree of cloudiness (%)

In addition, this term was adjusted for the albedo of a dry concrete surface. The other terms in the heat balance equation were defined with respect to surface temperature and climatic conditions in the previous section. The heat loss due to evaporation was neglected because the analysis was performed on a dry concrete surface.

Figure II-1 is a plot of the annual energy dissipation as a function of surface temperature for typical climatic conditions in Baltimore and Syracuse. It can be observed that the thermal losses are considerably greater in more severe climates. For example, when the surface temperature is maintained at 50°F, the annual thermal losses will total 32 Kw-hrs/ft^2 in Baltimore as compared to 69 Kw-hrs/ft^2 in Syracuse. Figure II-2 shows the amount of energy dissipation on a monthly basis for the two locations when the surface temperature is held at 50°F. As can be expected, the majority of the thermal losses occur during the winter months of December, January, and February with additional losses occurring in March and November in the Syracuse climate.

C. Pavement Thermal Distribution as a Function of Pipe Spacing, Surface Condition, and Pavement Conductivity

An important aspect in the modeling of an actively heated concrete slab is the determination of the effects of basic design variables and concrete properties on the system performance. For this purpose, a two-dimensional nodal network model was developed using the computer program THERMO (originally developed at Goddard Space Flight Center in the early 1960's). A schematic representation of this network is shown in Figure II-3. The assumed depth of the model is 3 inches. Basically, for a steady-state problem, this program requires inputs of two boundary temperatures, nodal conductance connections, and conductance values. The nodal conductance values are defined by the network geometry and pavement conductivity. For those nodes adjacent to the heat pipe,

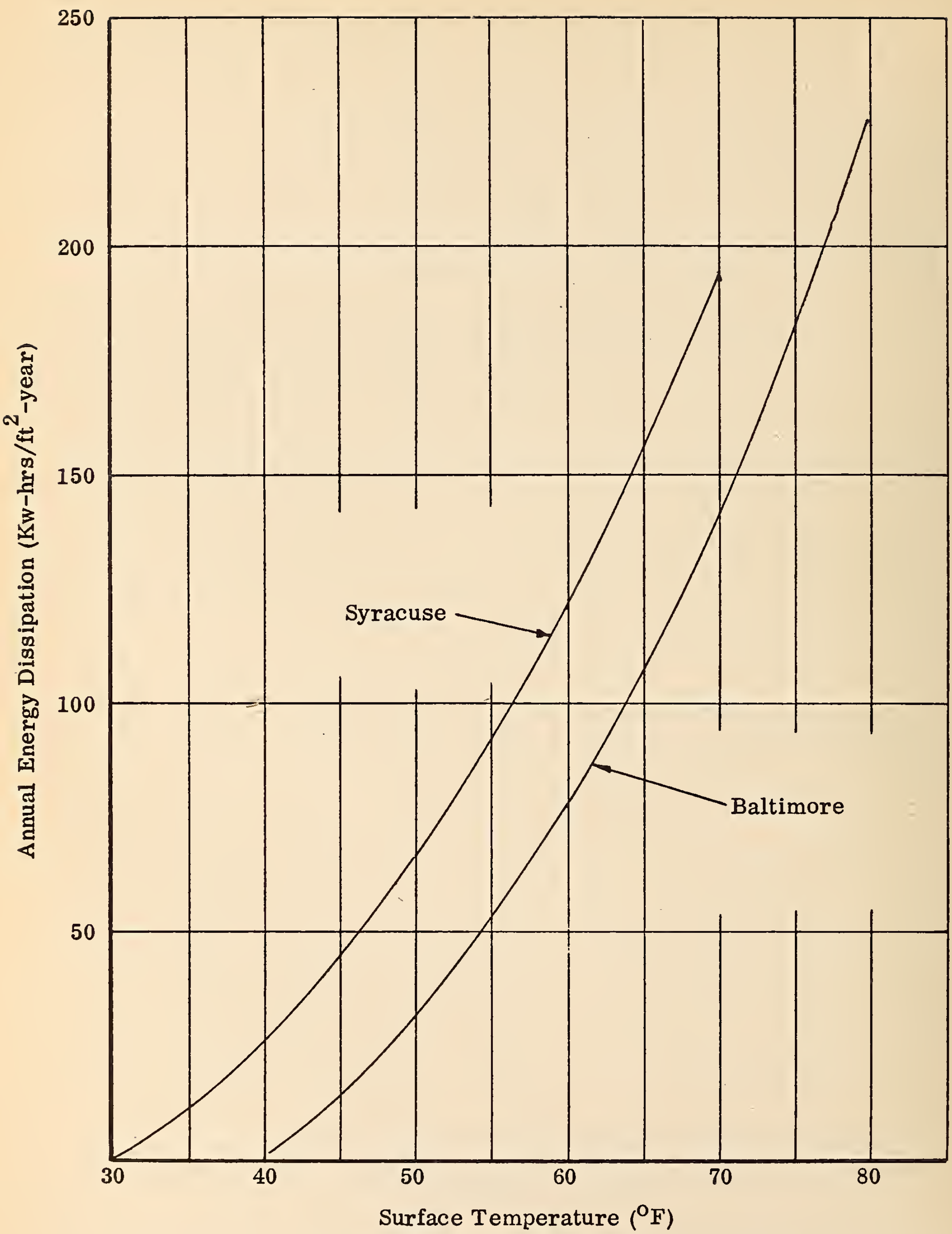


FIGURE II-1

ANNUAL ENERGY DISSIPATION AS A FUNCTION OF SURFACE TEMPERATURE

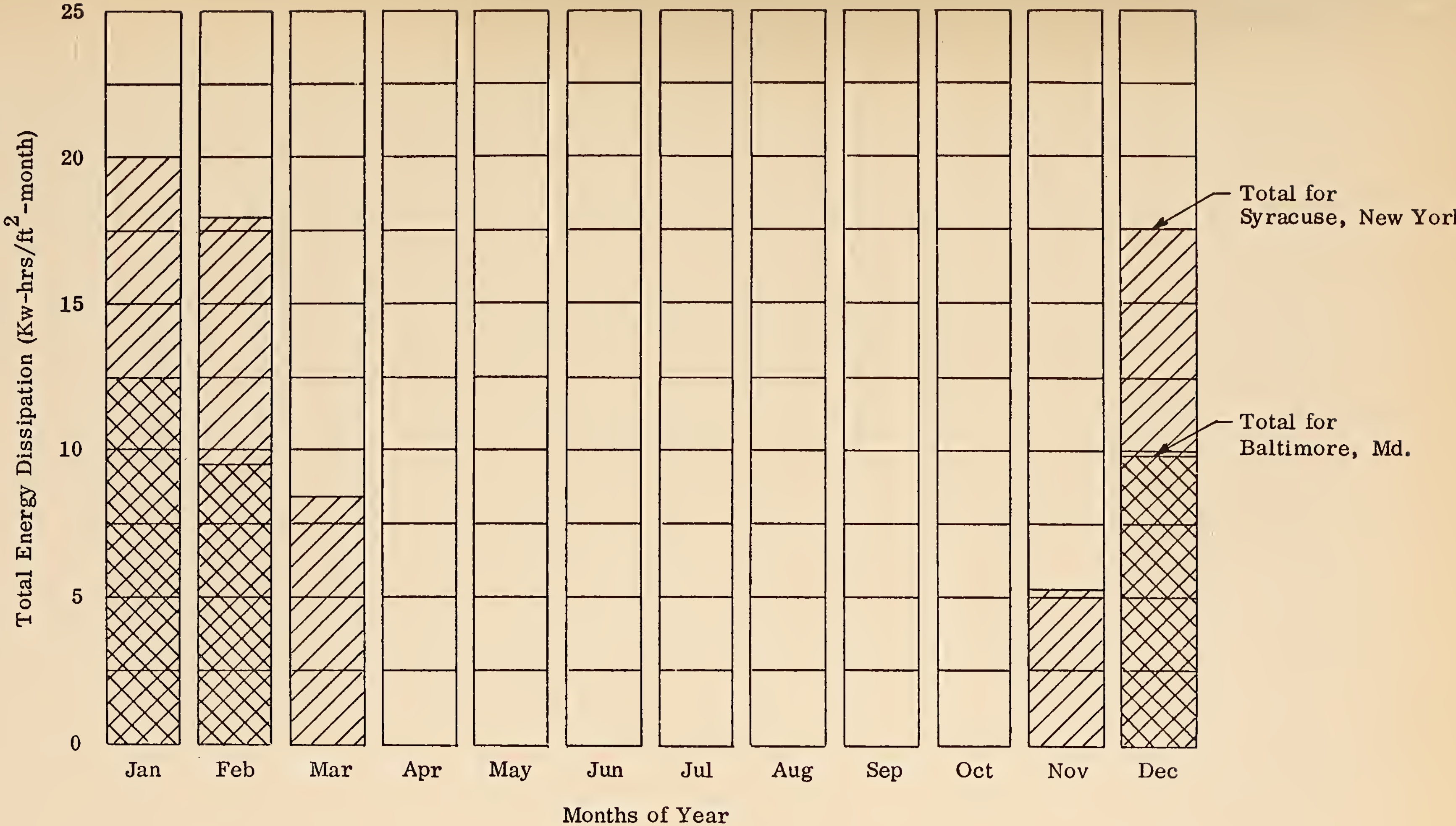


FIGURE II-2

TOTAL ENERGY DISSIPATION PER MONTH FOR A SURFACE MAINTAINED AT 50°F

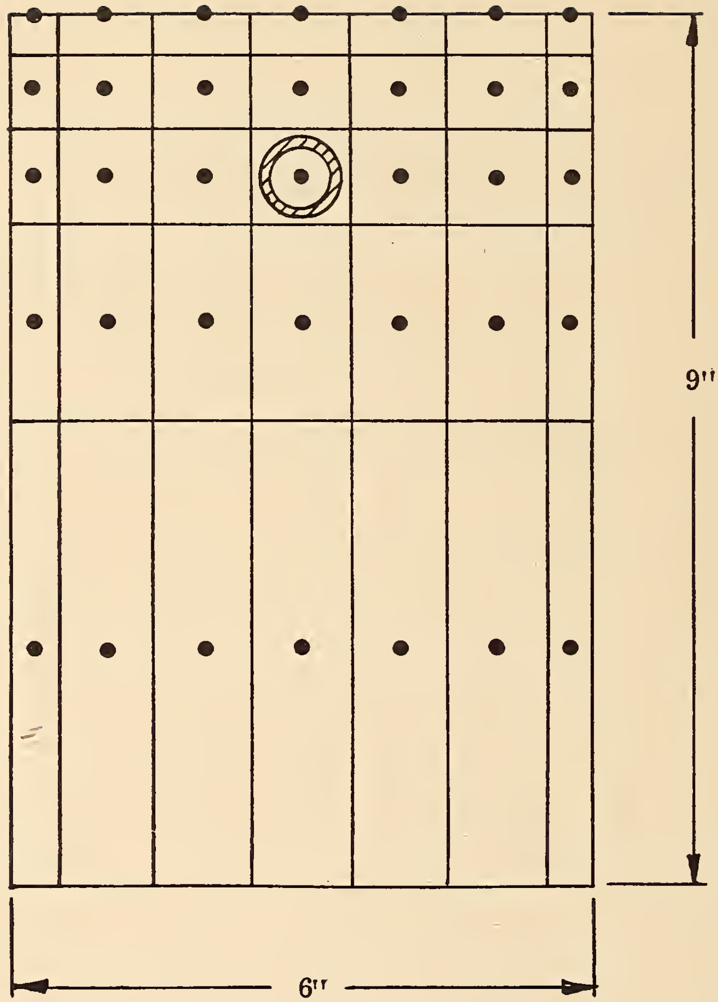


FIGURE II-3

NODAL NETWORK MODEL

the conductance values must account for the interface resistance between the concrete and the heat pipe. However, from experimental results (see Section V), it was found that the interface resistance was negligible. The earth source temperature is used as one boundary temperature, and the ground-concrete interface nodes can be coupled to this boundary to simulate the heat exchange between the ground and the slab. To model an earth heat pipe system, the heat pipe node can also be coupled to this earth source temperature; whereas modeling an electrical heat pipe slab, with a fixed power into the heat pipe, an internal dissipation must be assigned to the heat pipe node.

In addition, when modeling a dry slab, the pavement surface nodes are coupled to the ambient temperature, which represents the remaining boundary temperature. The conductance values for these connections are determined by the equations for the thermal losses applying to a dry surface. In the model for a wet surface with melting snow or ice, the surface nodes are coupled by large conductances to a sink temperature of 33^{o}F. These large conductances provide a simulation of the temperature flattening effects on the surface of the melting surface covering.

In order to determine the effects of surface condition on the thermal distribution in the pavement, this model was run for a heat pipe spacing of 6 inches, a heat pipe input corresponding to an average surface flux of 10 watts/ft^2, and a concrete conductivity of 1.0 Btu/hr-ft-^{o}F. The temperature variation at the surface perpendicular to the axis of the pipe, for a dry and wet surface, is shown in Figure II-4. For the wet surface, simulating melting, the surface temperature is isothermal at 33^{o}F. In the dry case and for an ambient temperature of 33^{o}F, the surface temperature is approximately 41^{o}F and is 1.8^{o}F greater directly above the heat pipe than between heat pipes.

Even more important is the difference in the surface flux variation between the

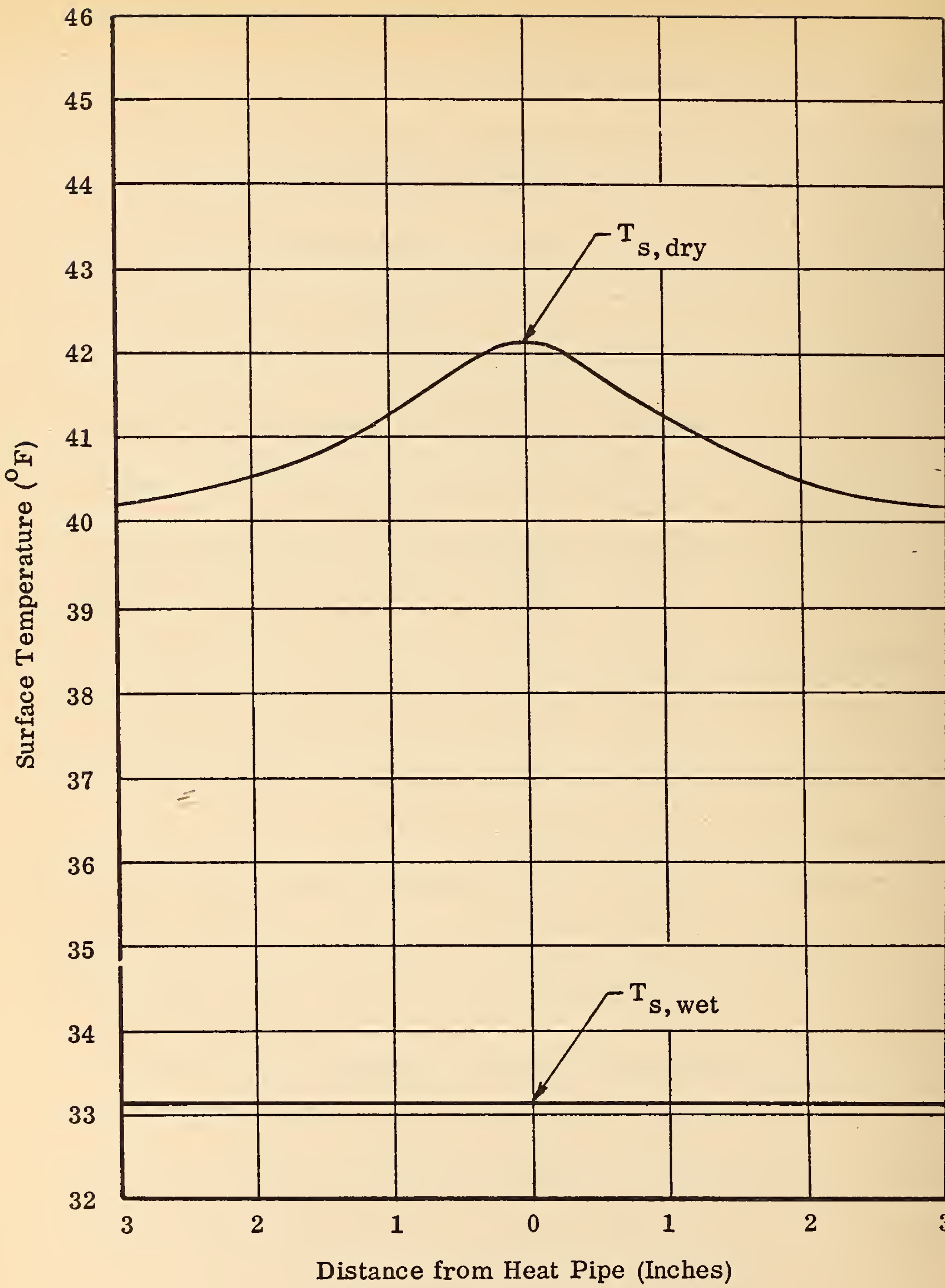


FIGURE II-4

SURFACE TEMPERATURE VARIATIONS FOR DRY AND WET SLABS

wet and dry case shown in Figure II-5. The surface flux in the wet case is much greater in the region directly above the heat pipe, which is indicative of the poorness of concrete as a conductor. This flux distribution could result in the formation of snow or ice ridges between heat pipes. The more evenly distributed surface flux demonstrated for a dry surface emphasizes that the surface to ambient resistance is the dominant component of the total resistance path from the heat pipe to ambient.

This model was also used to determine the effects of pipe spacing and pavement conductivity on the thermal distribution within the pavement. Figure II-6 shows the effects of conductivity and spacing on required heat pipe temperature as a function of surface flux. For a specified surface flux, the corresponding heat pipe temperature decreases as conductivity increases. This figure also demonstrates that, for a constant surface flux, heat pipe temperature increases as spacing increases.

The use of figures such as this is instrumental in the design of actively heated concrete surface. Once the required surface flux has been established and the pavement conductivity is known, the heat pipe temperature can be determined for a specified spacing. For an electrically heated slab, the required heat pipe temperature is not a critical parameter since it will adjust automatically to the required value for the existing pipe spacing and pavement conductivity. Only practical considerations, such as system installation and cost, allowable extent of snow ridge formation, reliability, and stress levels in the concrete, influence system design. However, for an earth heat pipe slab, the heat transport capability of heat pipes is directly related to heat pipe temperature. The magnitude of the heat pipe flux is determined by the temperature of the ground source, the heat pipe temperature, and the thermal resistance between the two temperatures. Thus for an earth heat pipe slab, as the heat pipe spacing increases, the

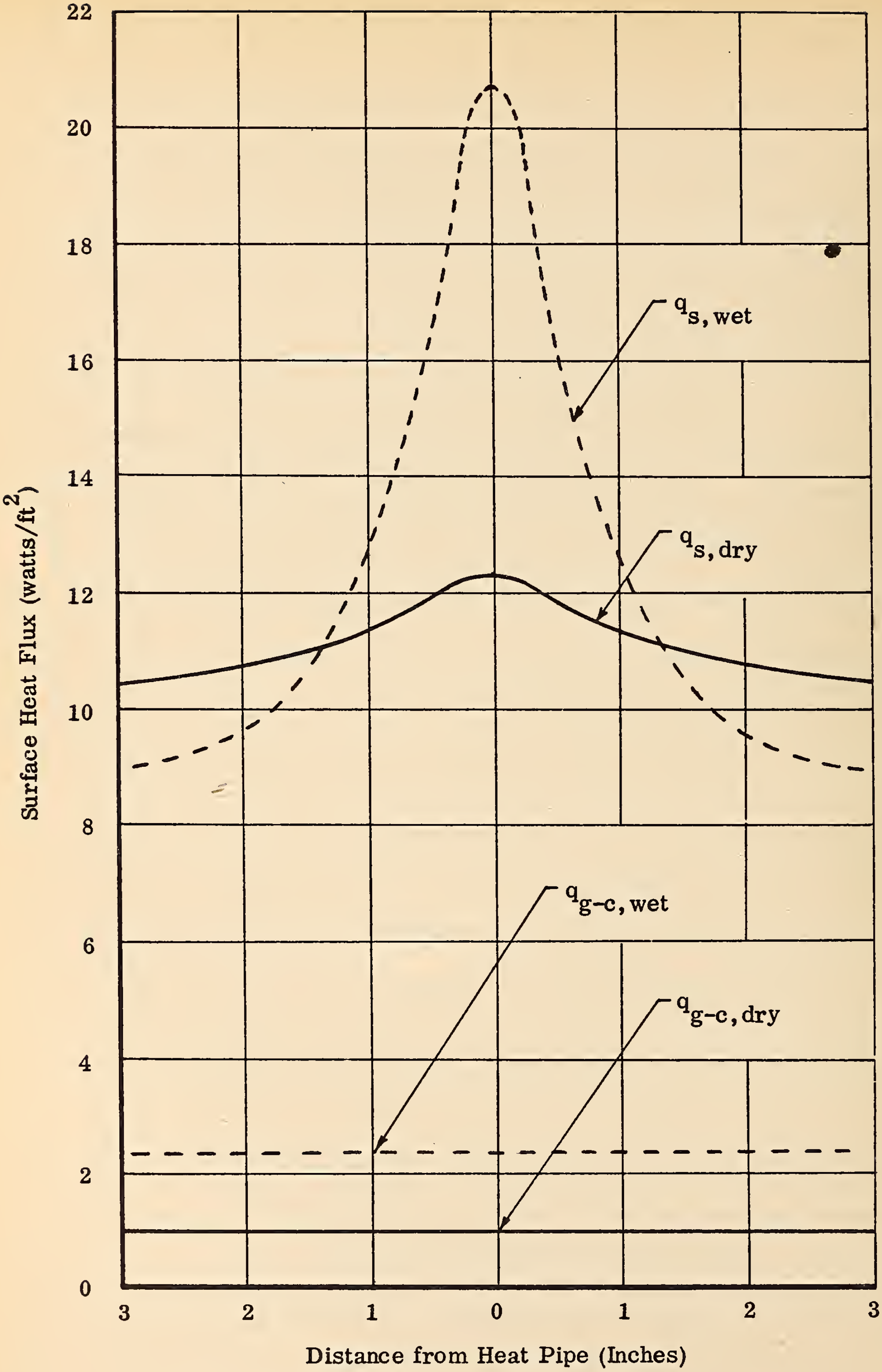


FIGURE II-5

SURFACE HEAT FLUX DISTRIBUTION ON DRY AND WET SLABS

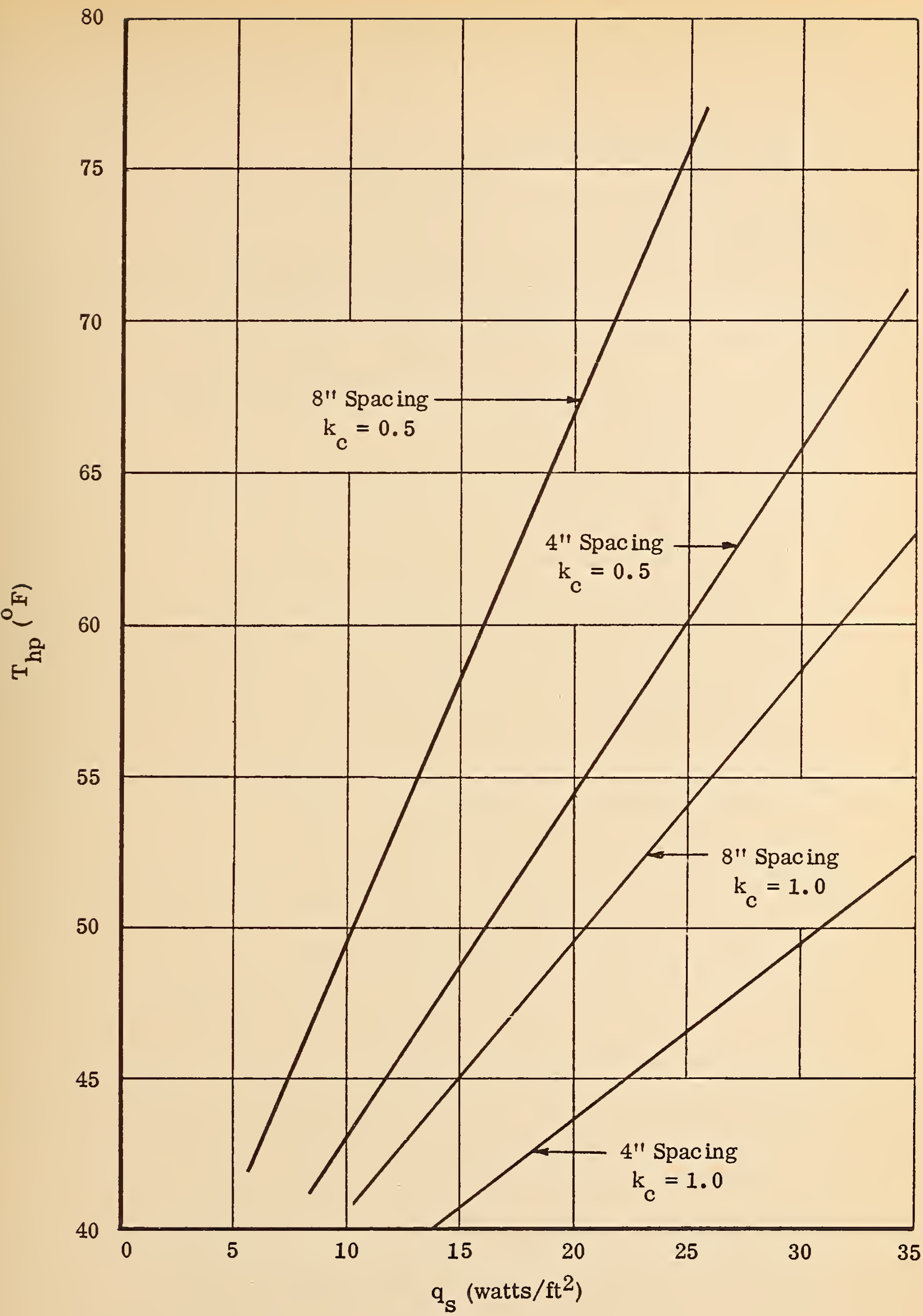


FIGURE II-6

EFFECTS OF HEAT PIPE SPACING AND CONCRETE CONDUCTIVITY ON HEAT PIPE TEMPERATURE

depth to which the heat pipe must extend must increase to yield a constant heat pipe flux. This consideration, in addition to those mentioned for the electrical slab, constitute the basis for the design of a earth heat pipe slab.

D. Earth Source Behavior

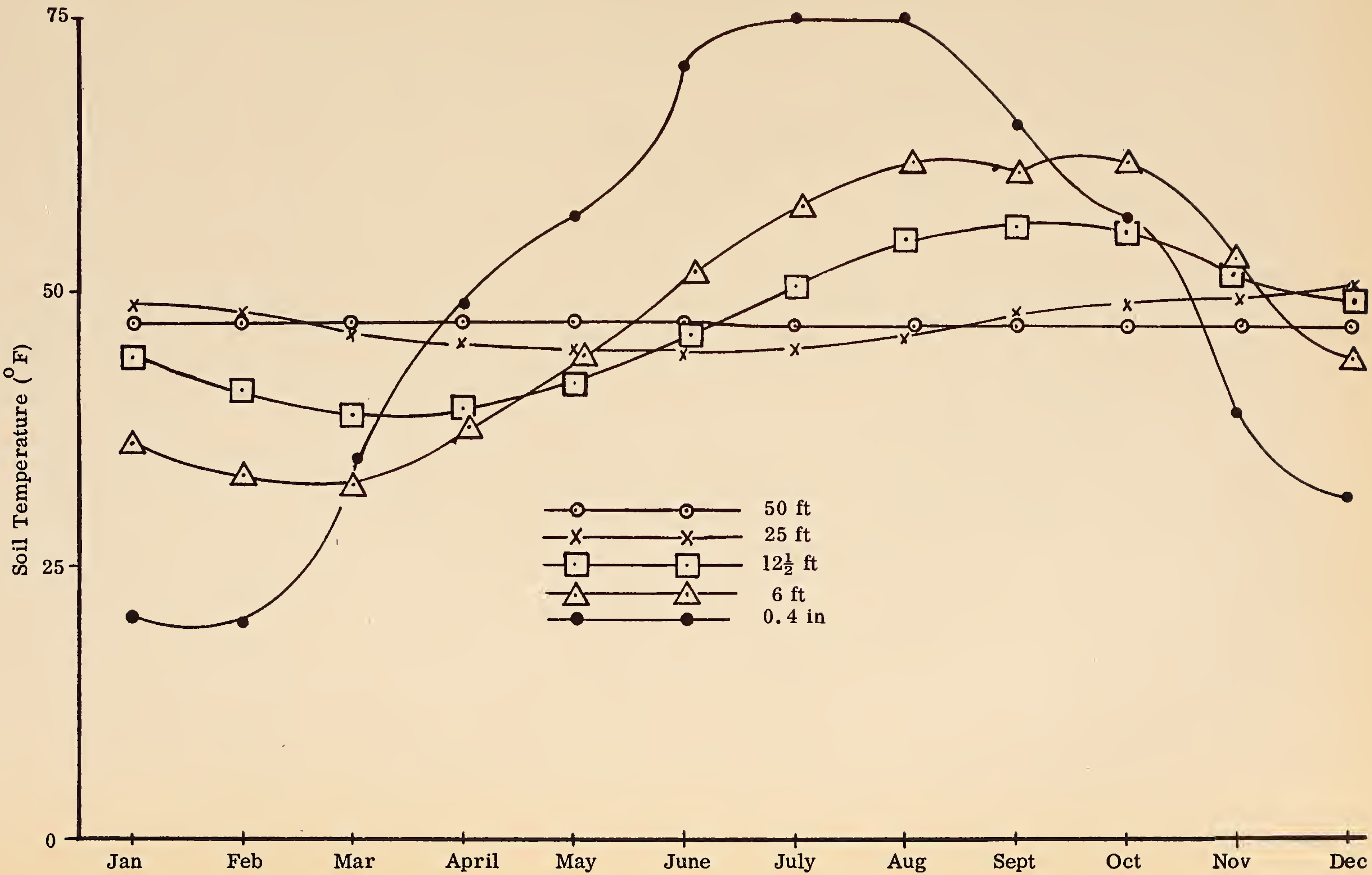
The use of large volumes of earth as an energy source is consistent with the ever increasing need to conserve the world's energy resources. Since the heat pipe is an essentially isothermal heat transfer device, it is possible to effectively utilize this low grade energy source.

The yearly average temperatures can be utilized in estimating the feasibility of an earth reservoir system for specific locations. At depths of 25 feet or greater, the average soil temperature approximates the yearly average ambient temperature. Figure II-7 shows the results of monthly measurements made at the University of Minnesota of the ground temperature variation as a function of depth. It can be observed from these curves that, at a depth of 25 feet, the deviation from the average value is approximately $\pm 2^{o}$F. It can also be noted that the response of the soil temperature lags behind the ambient temperature. This means that the potential for heat transfer will not drop off sharply as the winter progresses.

In addition to temperature, other soil properties must be considered in evaluating the potential usefulness of the earth at a given location, as an energy source. The density, the percent moisture content, and the consistency all effect the thermal conductivity and the heat capacity of the soil. The thermal conductivity of soil increases with increasing density for a given moisture content and temperature. The thermal conductivity also increases with increasing moisture content for a given density and temperature. Temperature alone does not have a significant effect on the

FIGURE II-7

SOIL TEMPERATURE (UNIVERSITY OF MINNESOTA) VS. DEPTH



thermal conductivity of soil.

These trends can be observed in Figures II-8 and II-9. Figure II-8 presents the variation of thermal conductivity of silts and clay soil with dry density for moisture contents of 10%, 15%, and 20%. Figure II-9 presents the variation of thermal conductivity with dry density for sandy soils at various moisture contents. These curves are based on laboratory testing conducted at the University of Minnesota (Reference 5).

The thermal conductivity varies with the texture of soil. For a given density and moisture content, the conductivity is relatively high for coarse textured soils such as sand or gravel, somewhat lower for sand loam soils, and lowest for fine textured soils such as silt loam or clay. A comparison of the sets of curves in Figures II-8 and II-9 verifies this relationship. For example, for a dry density of 100 pcf and a moisture content of 10%, the thermal conductivity of a sand soil is 11 Btu/ft^2-hr-^{o}F-inch compared to 7 Btu/ft^2-hr-^{o}F-inch for a silt and clay soil. On the natural environment in the field, this order would not necessarily hold since finely textured soils ordinarily contain a higher moisture content than sandy soils.

The thermal conductivity of a soil is also dependent upon its mineral composition. Sands with a high quartz content have greater conductivities than sands with high contents of such minerals as plagioclase, feldspar, and pyroxene, which are constituents of basic rocks. Soils with a relatively high content of kaolinite and other clay minerals have relatively low conductivities. This may be due to the fine texture and is not necessarily the result of the presence of these minerals.

The specific heat of a soil is highly dependent upon the moisture content for a given dry density. This relationship is defined by the equation (Reference 5):

$$C_{p\ mixture} = \frac{(100 \times C_{p\ soil}) + w}{100 + w} \qquad \text{II-11}$$

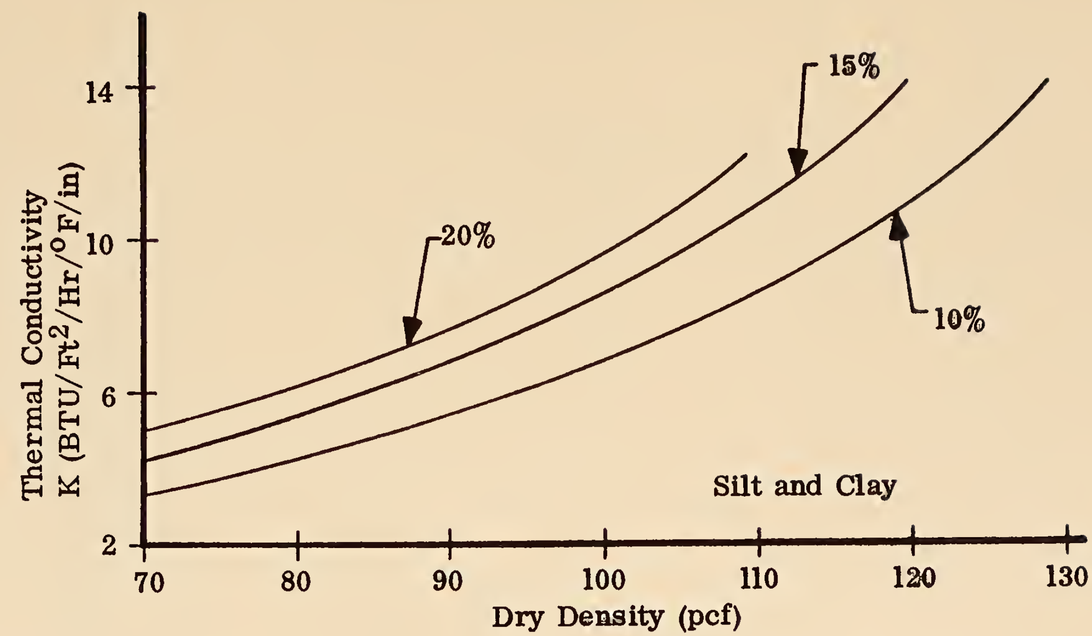


FIGURE II-8

VARIATIONS OF THERMAL CONDUCTIVITY OF SILT AND CLAY SOILS WITH DRY DENSITY FOR VARIOUS MOISTURE CONTENTS

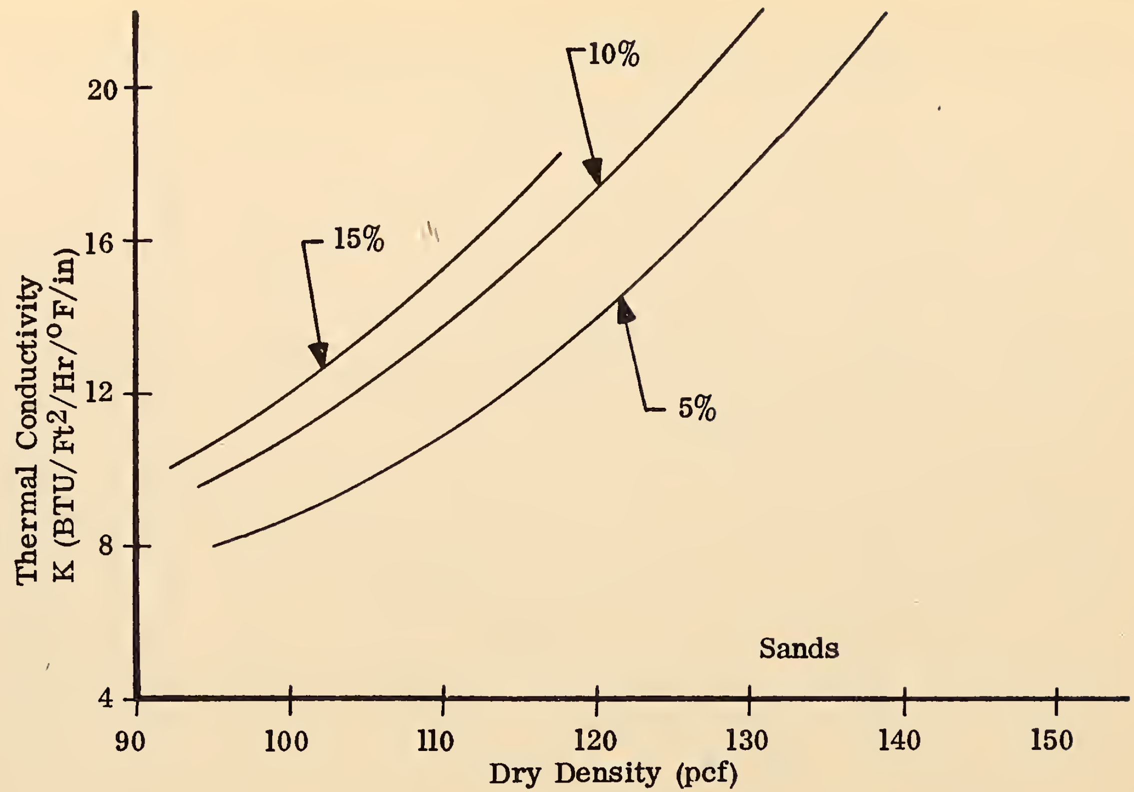


FIGURE II-9

VARIATIONS OF THERMAL CONDUCTIVITY OF SANDS
WITH DRY DENSITY FOR VARIOUS MOISTURE CONTENTS

where: C_p = specific heat (Btu/lb-^{o}F)

w = percent moisture content

The average heat capacity of dry soils is approximately 20 Btu/ft^3-^{o}F. However, for moisture content of 26%, this value would increase 100% to 40 Btu/ft^3-^{o}F.

In areas where earth heat pipes are used for pavement deicing, the earth heat contained in the volume of earth adjacent to the earth heat pipes is continually being pumped to the surface during the winter months. Here, it is used to melt snow and ice or is otherwise dissipated to the environment. To assure an adequate supply of earth heat for the next Winter, this energy must be replenished during the summer months.

As noted previously, the soil temperature is an important parameter in determining the amount of available energy. If the heat capacity and the volume of the soil coupled to the earth heat pipes is specified, the amount of energy dissipated can be determined by the drop in the average soil temperature. Since the difference in temperature between the ambient and the earth provides the driving potential for heat transfer, this difference must be maintained from year to year. That is, the average earth temperature, which will drop off as energy is dissipated during the winter months, should recover during the summer months to the level of the previous year.

At the Fairbank Test Site, there are three Instrumentation Poles which are capable of monitoring the temperature of the earth from ground level to a depth of forty feet. Figure II-10 shows the relative location of these Poles. Instrumentation Pole A is located adjacent to the Control Slab, Pole B is located within the Earth Heat Pipe field, and Pole C is located 60 feet away from the Earth Slab. The amount and nature of earth heat recovery at the test site can be determined by monitoring the earth temperature

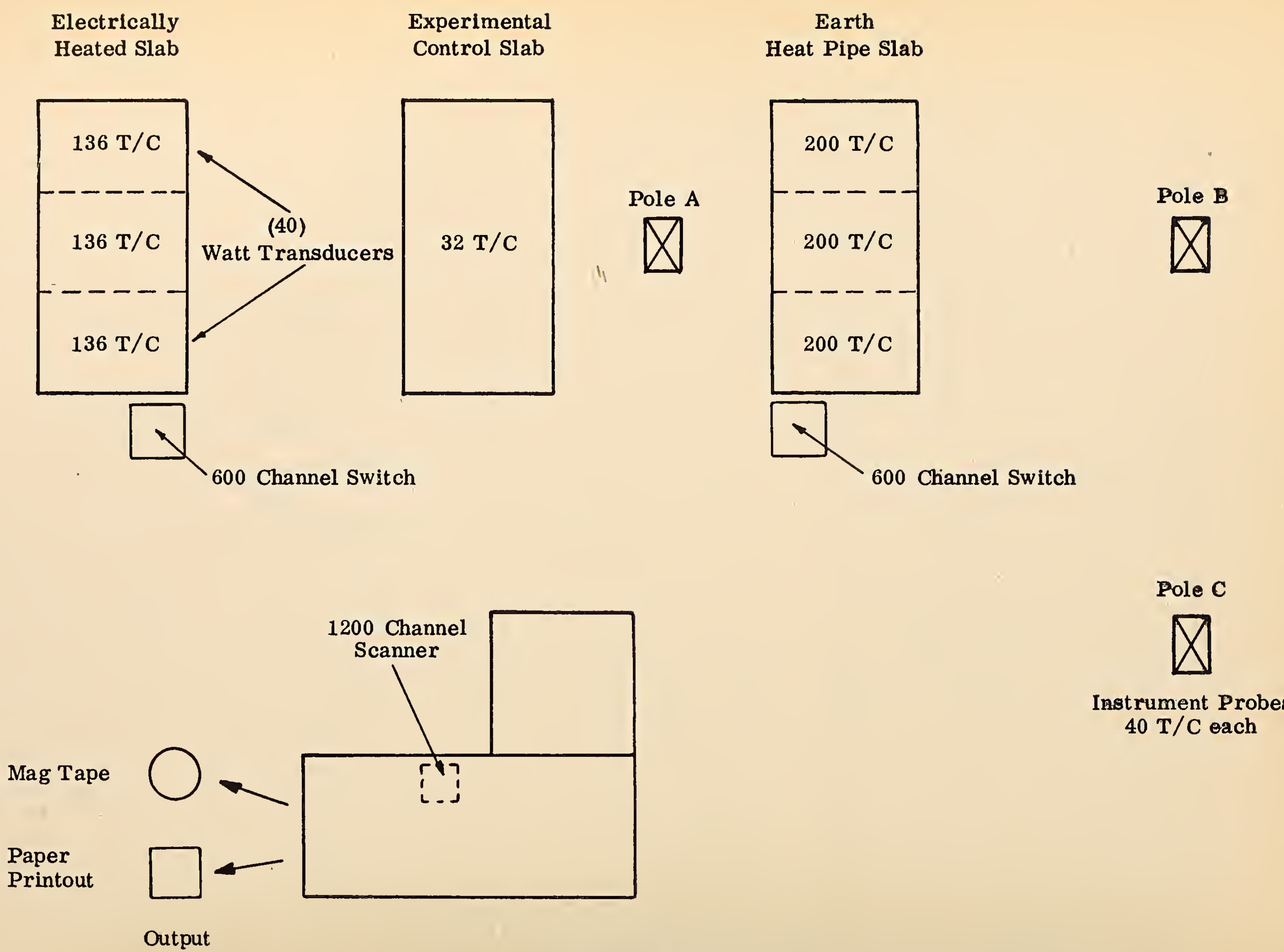


FIGURE II-10

INSTRUMENTATION ARRANGEMENT PLAN SCHEMATIC

profiles at these locations for a complete Winter-Summer cycle.

Figures II-11, II-12, and II-13 illustrate earth temperature profiles at Instrumentation Poles A, B, and C, respectively. Temperature profiles were recorded in the period from February 8, 1973 to February 8, 1974. The average variation of the profiles at the 20 to 40 foot depth is greatest at Instrumentation Pole B. This is to be expected, because Pole B is located within the earth heat pipe field where the earth heat removal during the winter months will occur.

At all three locations, the temperature profile at the 20 to 40 foot depth is slightly higher at the end of this one year cycle. At Instrumentation Poles A and C, the temperature profile is an average of 1^{o}F higher. At Instrumentation Pole B, the temperature profile is an average of 2^{o}F higher. This data demonstrates that the heat removed from the earth during the Winter is fully recovered during the Summer in a heat pipe field of this size.

E. Prediction of Temperature Distribution in Concrete Slabs with Transient Nodal Network Model

The prediction of the thermal behavior of a concrete slab can only be done with a transient mathematical model, not only because of the transient system response due to the mass of the system but also because of the transience of the ambient conditions to which the system must adjust. For these reasons, a transient nodal network model was developed. In addition to the input requirements of the steady-state model, this model requires a thermal capacitance and an initial temperature for each node. It is also possible to vary the sink conditions to model variations in ambient conditions.

As an example, this model was used to predict the thermal adjustment of an actively heated concrete slab subjected to the instantaneous addition of ice or snow.

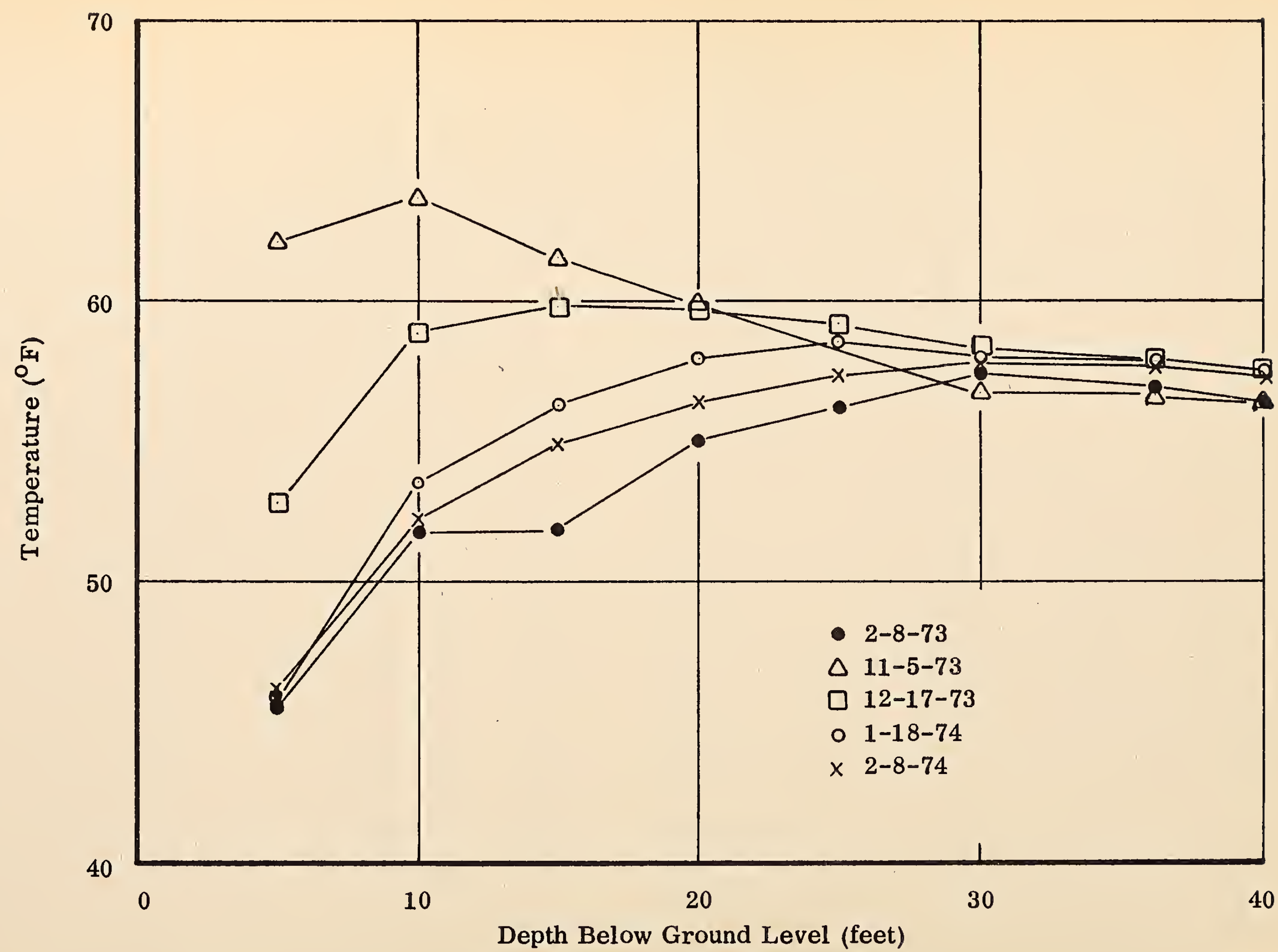


FIGURE II-11

EARTH TEMPERATURE PROFILE
INSTRUMENTATION POLE A

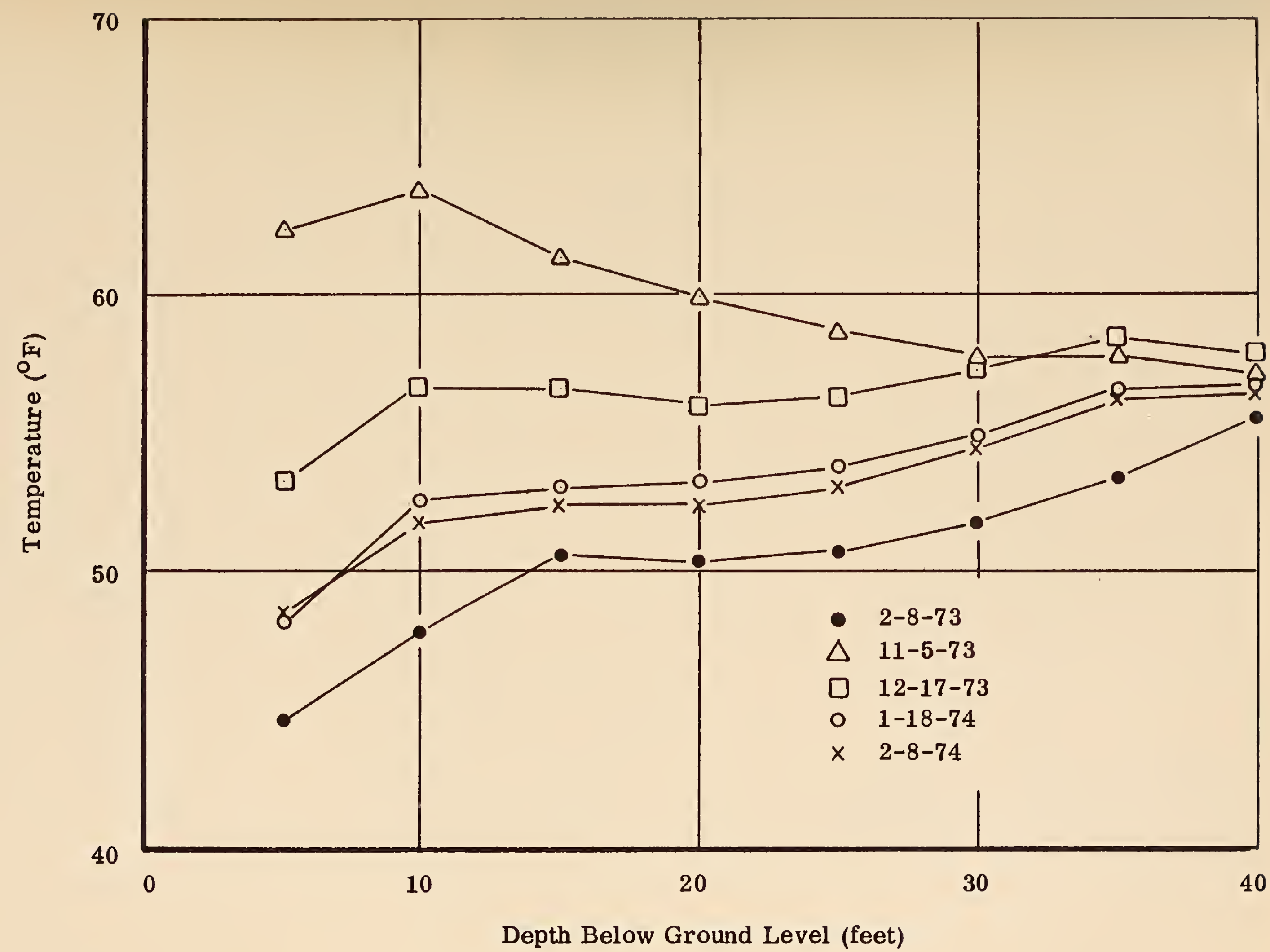


FIGURE II-12

EARTH TEMPERATURE PROFILE
INSTRUMENTATION POLE B

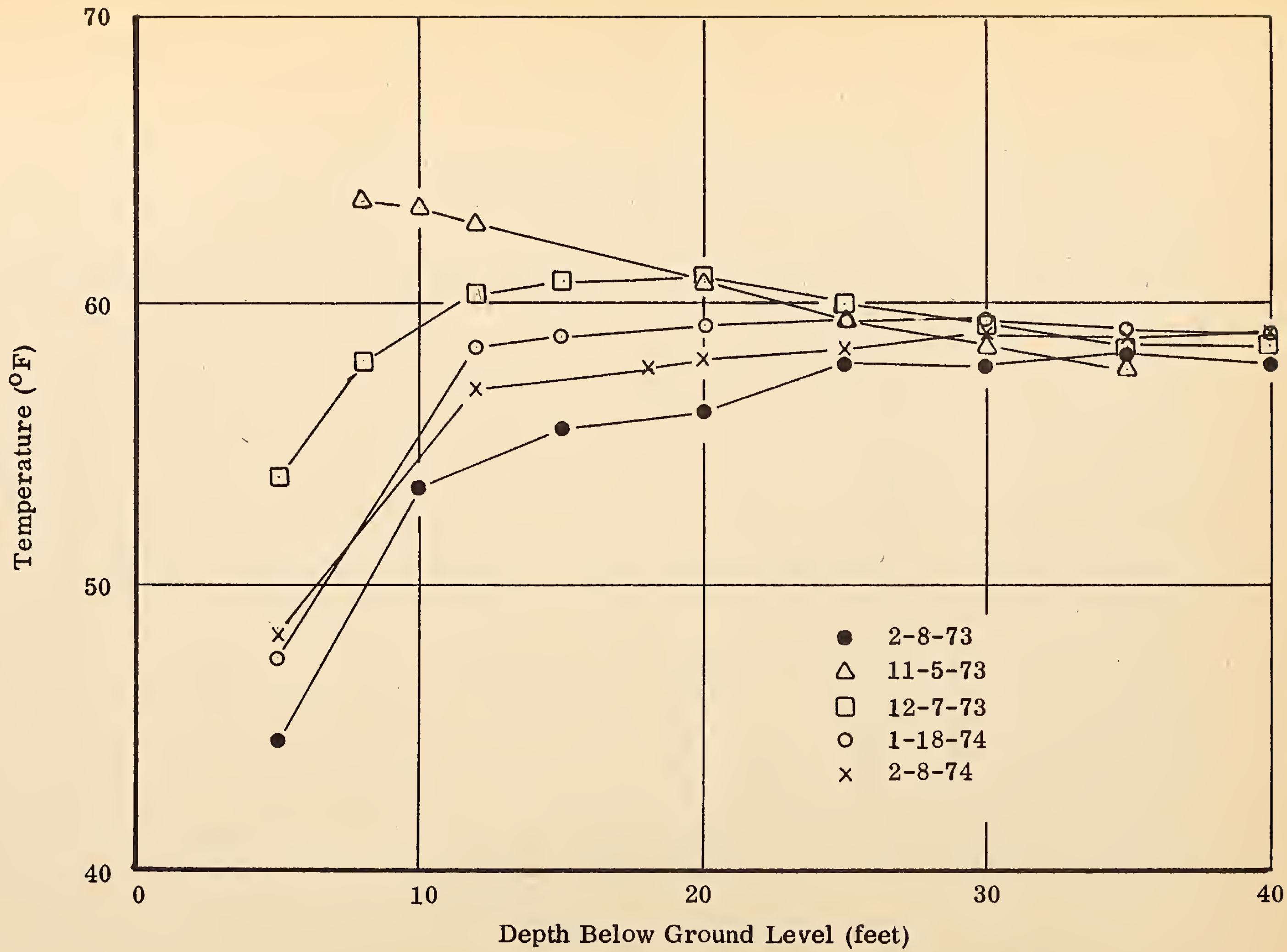


FIGURE II-13

EARTH TEMPERATURE PROFILE
INSTRUMENTATION POLE C

Heat pipe input was assumed to be constant and corresponding to a surface flux of 10 watts/ft^2, with a heat pipe spacing of 4 inches. Pavement conductivity was assumed to be 1.0 Btu/hr-ft-$^{\circ}$F. Ground source temperature was 56°F and sink temperature was 32°F. Conductance between the ground source temperature and pavement was assumed to be 1.73 Btu/hr-ft^2-$^{\circ}$F. The predicted temperature profile in the pavement midway between heat pipes, as a function of time, is shown in Figure II-14. According to the model, the pavement has still not fully adjusted to the imposed sink condition after a period of 6 hours. The predicted heat pipe temperature versus time, shown in Figure II-15, indicates a similar response of the system. A significant output of the model is the transient heat flux to the concrete surface. It can be used, in conjunction with the surface losses, to predict the rate of snow melting for a given initial condition and heat input. In the case of an earth heat pipe system, the constant heat input into heat pipes is replaced by a conductive coupling to the ground source and transient adjustment of the concrete is calculated in a similar way.

The above two figures are the basis on which comparison between the actual and predicted system behavior can be made. Once the transient mathematical model has been validated by test results, it can be used as an analytical tool for the design of an actively heated pavement system.

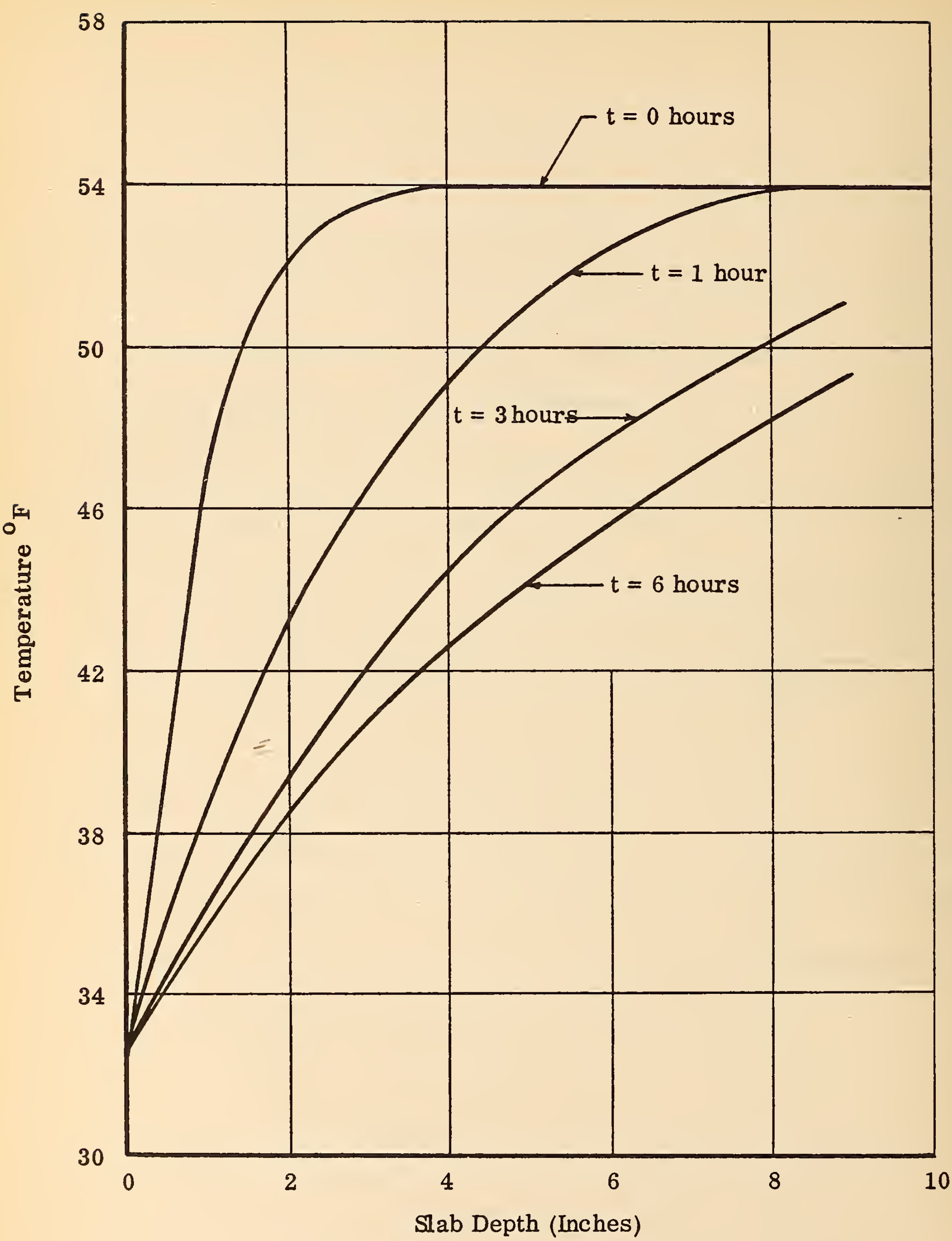


FIGURE II-14

PREDICTED TEMPERATURE PROFILES IN ELECTRICALLY HEATED SLAB WITH INSTANTANEOUS ICE ADDITION

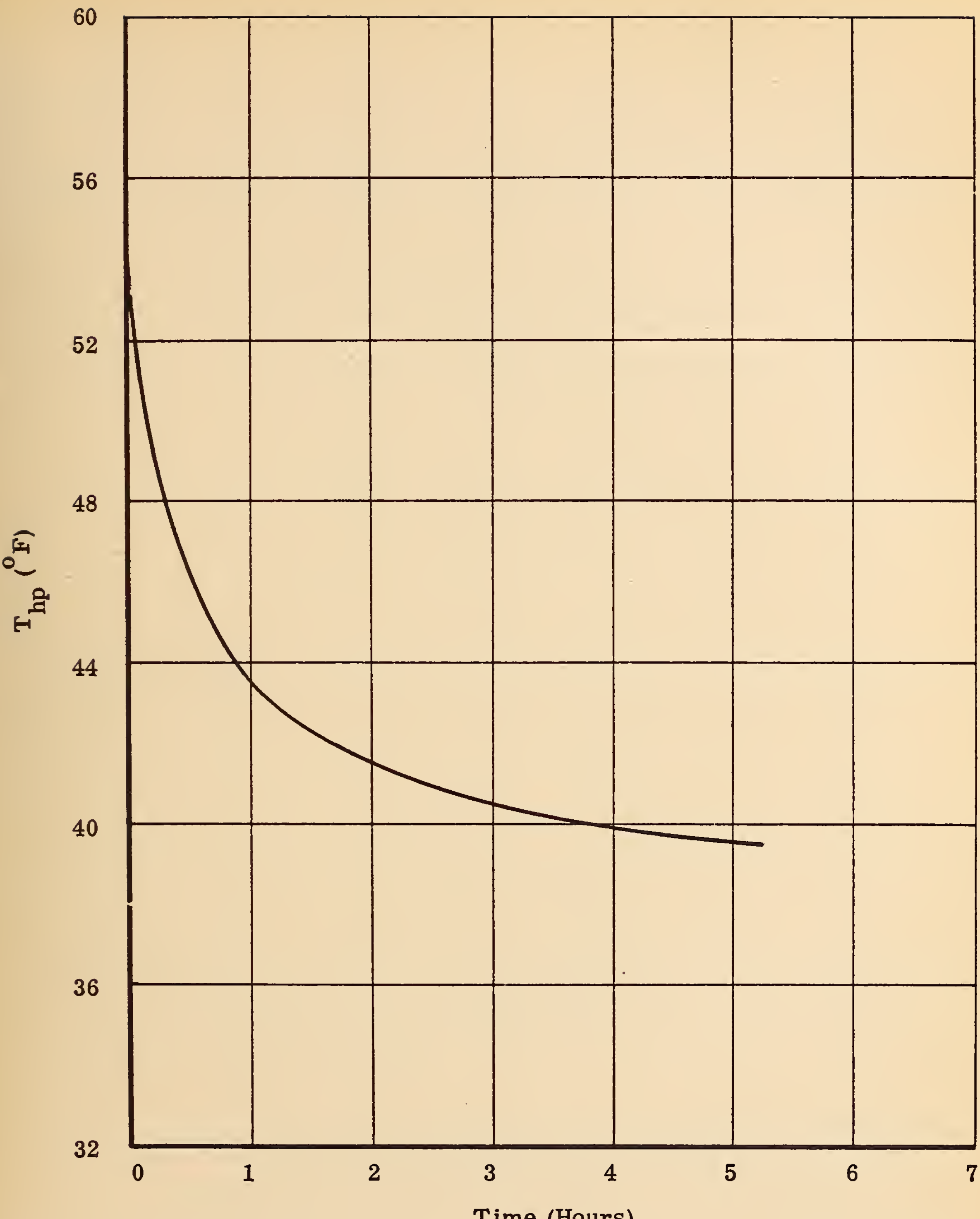


FIGURE II-15

PREDICTED HEAT PIPE TEMPERATURE VS. TIME FOR ELECTRICALLY HEATED SLAB WITH INSTANTANEOUS ICE ADDITION

III. COMPONENT TESTING AND RESULTS

A. Iron-Ammonia Compatibility Tests

To ensure an adequate system lifetime, compatibility must be established between heat pipe working fluid, wall material, wick material, and weld or brazing material. The use of materials which are incompatible may affect the performance of the heat pipe in various ways. For example, if a chemical reaction occurs and one of the products of the reaction is a noncondensible gas, it will separate from the operating fluid vapor and collect in the condenser and effectively reduce the condenser heat transfer area. Corrosion and erosion of the container and wick can also result in a change in the wetting angle of the working fluid as well as alter the permeability, porosity, and capillary pore size of the wick. Solid precipitates, resulting from corrosion and erosion, are transported by the working fluid to the evaporator region where they are deposited when the liquid vaporizes. This leads to an increased resistance to fluid flow in the evaporator which results in lowering the Heat Flux Limit in the evaporator.

Extensive experimental testing has been conducted by Dynatherm to verify the compatibility of the iron-ammonia system. Figure III-1 shows a section of a black-iron pipe that was operated for 2700 hours as a heat pipe using NH_3 (ammonia) working fluid. The section exhibited no evidence of corrosion. Other experimental verifications of the $Fe-NH_3$ compatibility include:

- A $Fe-NH_3$ heat pipe operated continuously at $100^{\circ}F$ for 35,000 hours has not exhibited any evidence of gas generation.
- A $Fe-NH_3$ heat pipe removed from Test Slab IV did not exhibit significant gas generation after 14,000 hours.

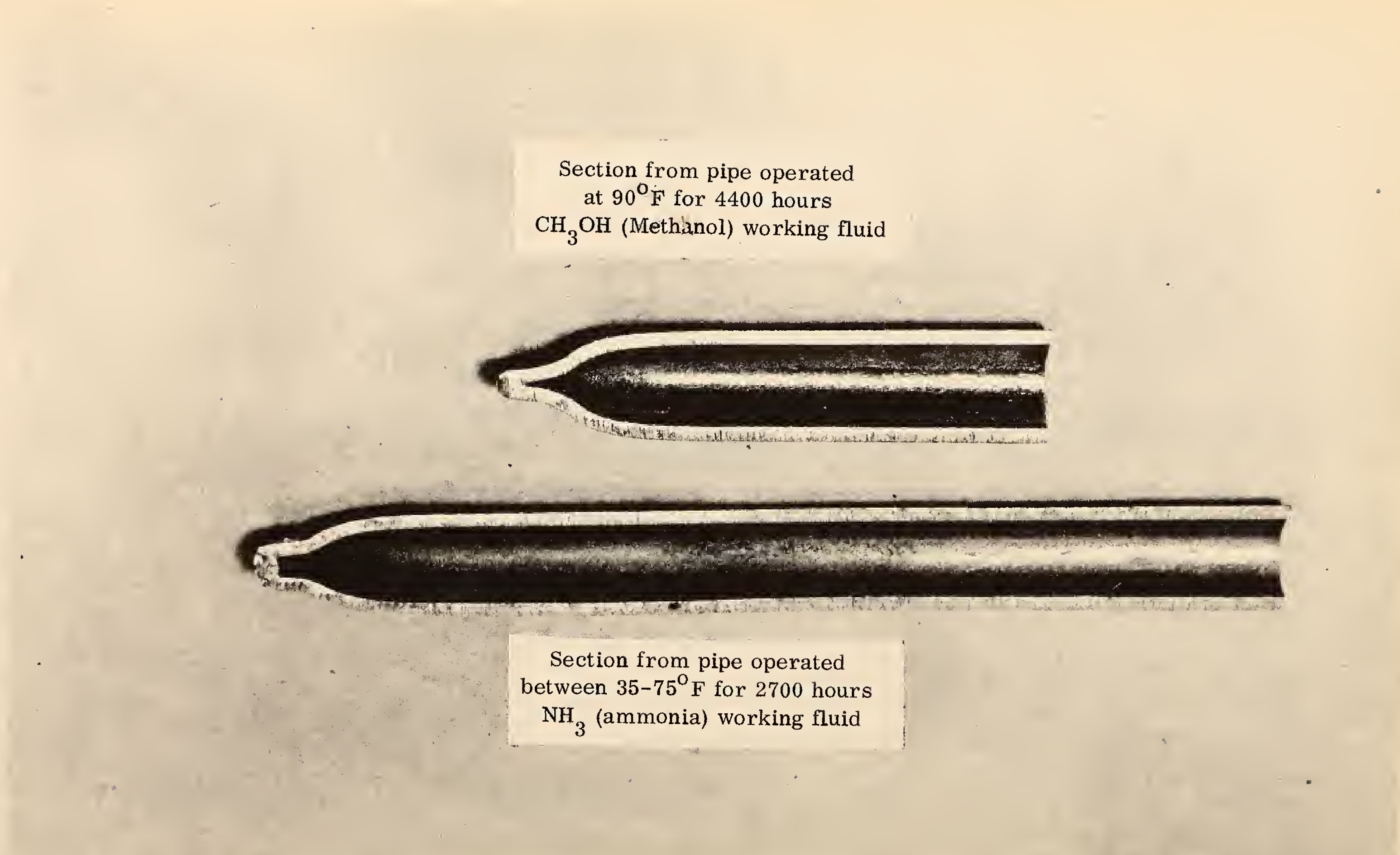


FIGURE III-1

HEAT PIPE TEST SPECIMENS
(BLACK IRON, 1/2-INCH NOMINAL PIPE)

- Accelerated life testing was performed on nine $Fe-NH_3$ heat pipes for the Alaskan pipeline application. All results indicated an insignificant amount of gas generation.

Several of the iron-ammonia pipes embedded in the test slabs at the Fairbank Test Site did exhibit condenser blockage resulting from gas generation. However, this blockage occurred in varying degrees, which indicated that noncondensible gas generation is not an inherent problem of the $Fe-NH_3$ heat pipe system. If the gas generation was due to material incompatibility, it would occur in all cases and to a relatively equal extent. Rather, it is likely that the gas generation was due to impurities which were present in the iron pipe. At the time of fabrication, a cleaning operation was not performed on the Fairbank Earth Heat Pipes. If, for example, moisture was present in the pipes, gas generation would occur as a result of water-ammonia-iron chemical reactions. This has been demonstrated in laboratory life testing. It appears that the manufacture of the $Fe-NH_3$ heat pipes must incorporate a straightforward cleaning procedure similar to that used for the Alaskan pipeline heat pipes.

B. Small Slab Tests

Prior to the construction of the test facility at Fairbank Highway Research Station (FHRS), four small concrete slabs with integral heat pipes were fabricated at Dynatherm. The installation and the operating characteristics of the small test slabs were carefully observed in order to verify the procedures and setup to be used at the FHRS Test Site.

1. Test Slab I

This test assembly contained four electrically heated transporters arranged orthogonally with eight mat heat pipes. The transporters and heat

pipes were charged with methanol. The cast test slab measured 3' x 5' and incorporated two depths of concrete cover and two types of concrete (Wirand and Sakrete sand mix). The information yielded by this test slab resulted in design improvements for the field test. The value of placing vertical temperature probes in the concrete for analysis purposes was verified, and it was determined that a more durable thermocouple wire was needed for the instrumentation. Test results also indicated that the point contact between the transporters and mat heat pipes was not providing a good thermal contact.

2. Test Slab II

This concrete slab measured 17" x 29" x 6" and contained one transporter and one mat heat pipe that had been removed from Test Slab I. The testing of this slab verified that a high thermal resistance existed at the mat/transporter coupling. Following the testing, the slab was broken up and the recovered pipes were recast with a metal coupling between them. This provided a much more satisfactory thermal contact.

3. Test Slab III

Figure III-2 shows the arrangement of the two manifolded NH_3 heat pipe assemblies that were contained in Test Slab III. This configuration was evolved in order to study mat heat pipe performance independent of the transporter and coupling. Favorable results were obtained with this new configuration and a design study indicated that it was feasible for general application.

While testing this configuration at 22.5 Watts/ft^2, snow fell during the night and in the morning the surface of the slab was dry. To visually demonstrate

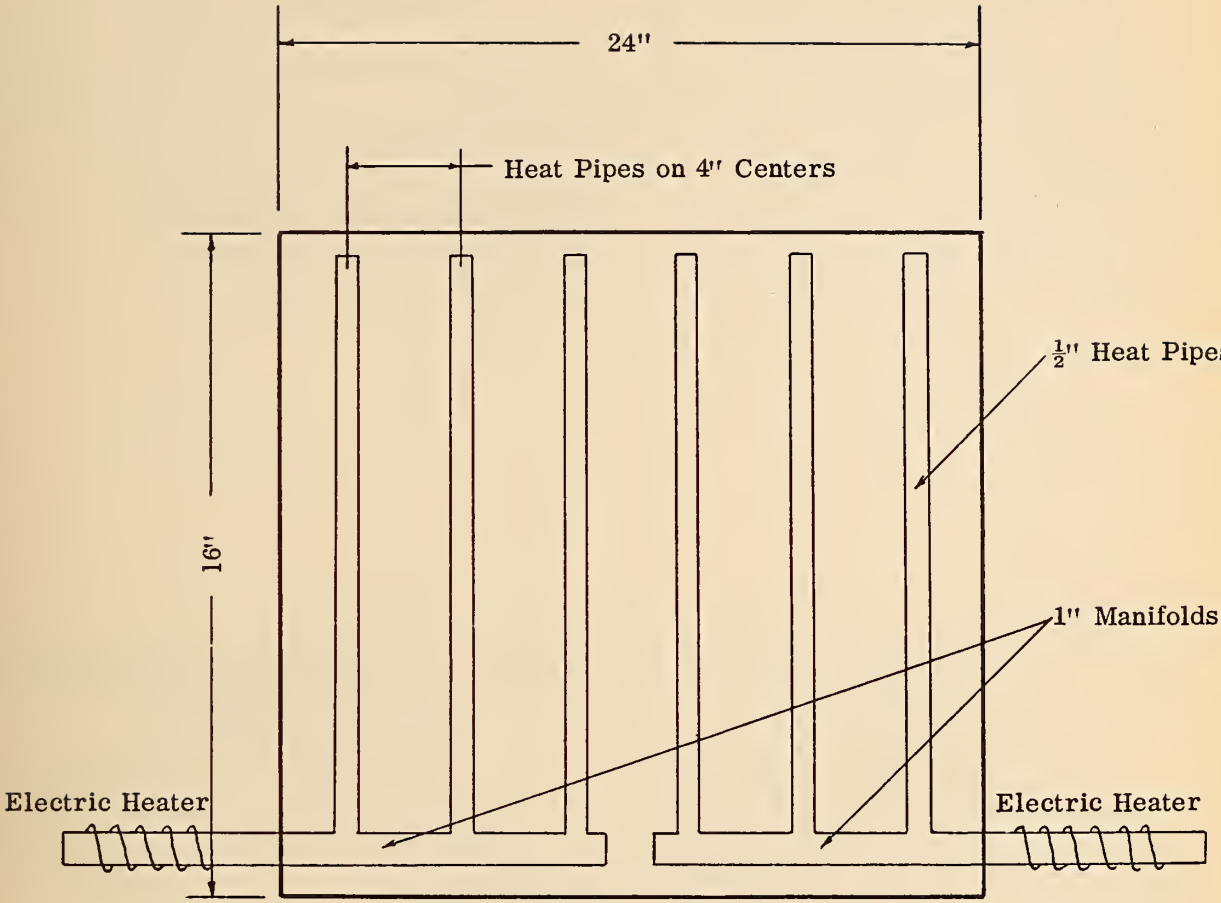


FIGURE III-2

TEST SLAB III - MANIFOLD NH_3 HEAT PIPES IN 6" THICK CONCRETE

the performance of the test slab, snow was placed on the slab surface and a sequence of photographs was taken during the subsequent melting (see Figures III-3 through III-5).

4. Test Slab IV

This slab measured 4' x 4' and contained four heat pipe assemblies. Two assemblies were identical, being three pipes spaced 4 inches apart and fed from a single manifold. These were a scale-up in length of the configuration used in Test Slab III. One manifold contained Freon-21 as the working fluid and the other contained NH_3 (ammonia). The third assembly consisted of a pair of heat pipes located 6 inches apart which were manifolded to a single driver, and the final assembly was a driver/mat heat pipe configuration. Ammonia was the working fluid for these latter configurations.

The test results indicated that a scale-up was feasible; and, therefore, the manifolding concept was incorporated in the Fairbank design. In addition, better performance was obtained with the NH_3 heat pipes. Therefore, ammonia was selected as the working fluid for the Fairbank test facility.

C. Prototype Earth Heat Pipe Tests

Several full-size earth heat pipes were tested at Dynatherm prior to the test site construction in order to verify their performance capabilities.

Figure III-6 shows a 60-foot long transporter heat pipe which was fabricated from one inch nominal black iron pipe and charged with methanol. Heat was applied by three strip heaters spaced along 20 feet of the 45-foot down leg. The entire down leg was insulated, and a circulating water tank was utilized to remove heat from the condenser leg.

A. Dry test slab prior to demonstration.
Air Temperature + 29°F
Electric Power Input - $22\frac{1}{2}$ W/ft^2

B. 09:12:00 (Time Zero)
Place 1.37# of snow on slab.

C. Time 09:12:55

D. Time 09:13:55

FIGURE III-3

SNOW MELT DEMONSTRATION

dynaTherm
Corporation

E. Time 09:16:55

F. Time 09:18:00

G. Time 09:19:55

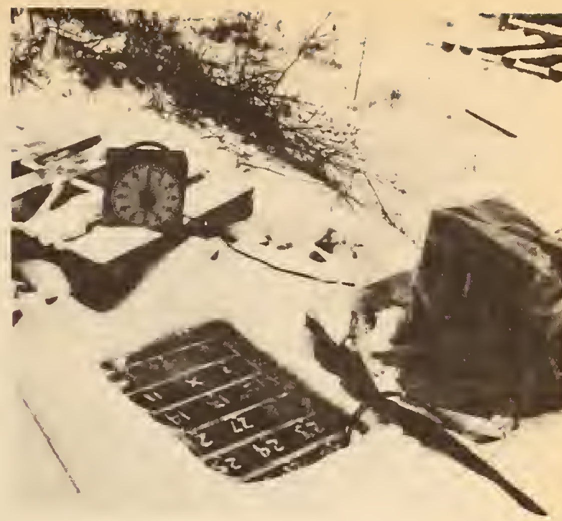
H. Time 09:21:55

FIGURE III-4

SNOW MELT DEMONSTRATION

dynatherm
Corporation

I. Time 09:26:55



J. Time 09:36:55

K. Time 09:51:55

L. Time 10:02:10
Total Elapsed - 50 min 10 sec

FIGURE III-5

SNOW MELT DEMONSTRATION

dynaTherm Corporation

FIGURE III-6

PROTOTYPE EARTH HEAT PIPE

The 45 foot length (foreground) is installed vertically in the ground. The 15 foot length delivers heat along the surface of the ground.

The heat pipe was operated in a gravity assisted mode at various powers up to 1.5 kilowatts and isothermal performance was demonstrated.

Figure III-7 illustrates schematically a one inch nominal black iron pipe with a 30-foot vertical leg that was placed in the earth at Dynatherm's facilities. The 4-foot horizontal leg was placed in an ice bath (see Figure III-8), and melt rate tests were conducted to determine the amount of heat being pumped from the earth. The pipe, initially charged with Freon-21, was evacuated after several melt tests, the earth temperature measured, the pipe recharged with NH_3, and more melt rate tests conducted. The test results indicated that the earth heat pipe was capable of pumping approximately 180 watts from the earth to the ice bath with both working fluids. The resistance from the ground to the earth heat pipe was found to be approximately $0.05^{\circ}F$/watt.

To verify the feasibility of an increase in length of the earth heat pipes, an 80-foot long one inch nominal heat pipe (shown in Figure III-9) was fabricated. This heat pipe, which was charged with NH_3, was capable of transporting one kilowatt over a distance of 75 feet at room temperature.

D. Wick Materials for Down-Pumping Pipes

In very severe climates, it will be necessary to augment the earth heat source. The method chosen to augment the earth heat source must be inexpensive, reliable, and preferably passive. Substantial quantities of heat are available during the summer months, including solar radiation. Since the roadway surface is a convenient collector of summer heat, the feasibility of transporting this heat into the earth storage reservoir was investigated.

Conventional heat pipes are not capable of pumping heat down for distances of more than a few inches. Therefore, a heat pipe which employs a closed arterial wick

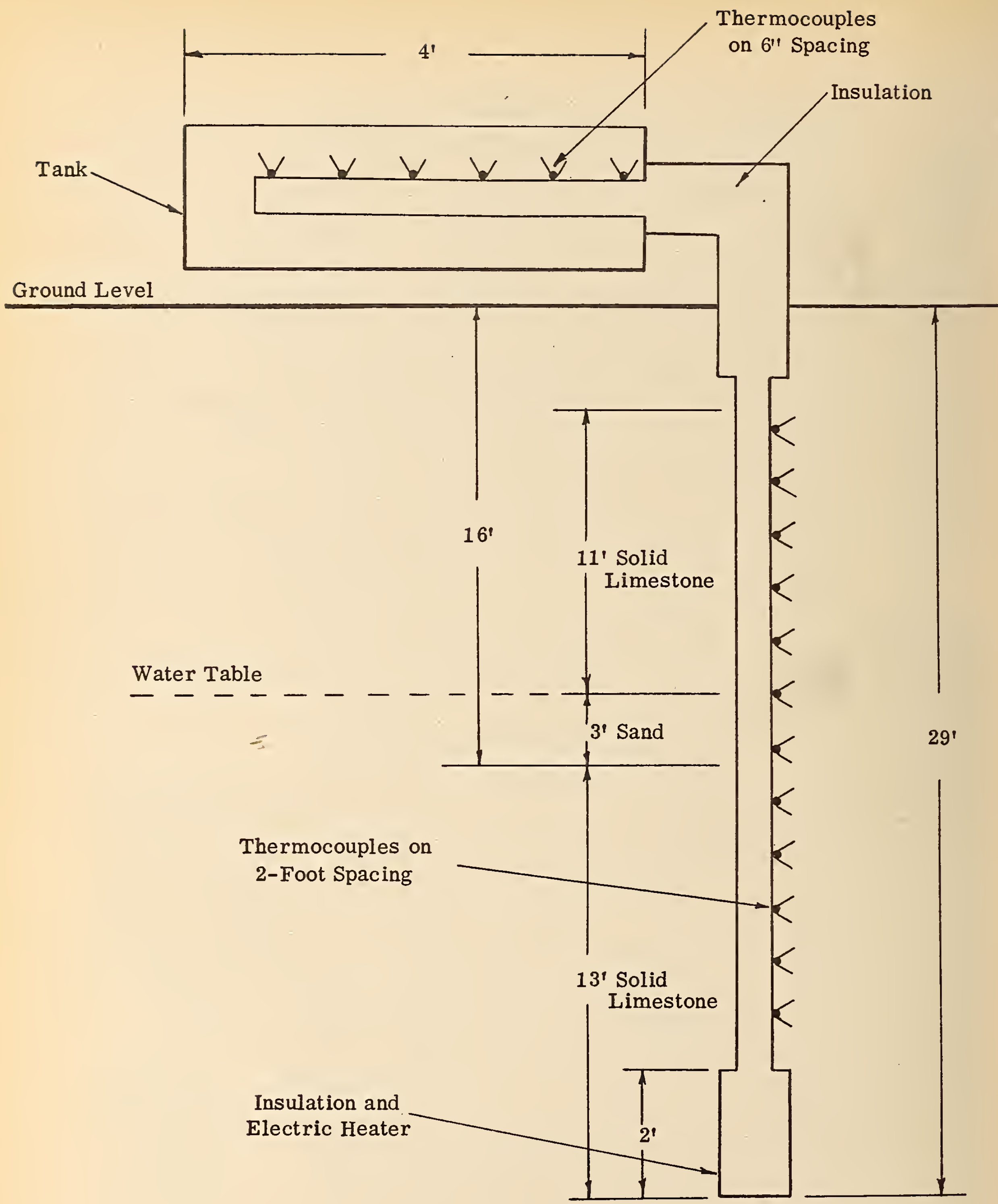


FIGURE III-7

SCHEMATIC OF PROTOTYPE EARTH HEAT PIPE TEST

FIGURE III-8

PROTOTYPE EARTH HEAT PIPE TEST ARRANGEMENT

The vertical leg of the heat pipe is 30 feet long. One foot of it is seen above ground at the right, where it meets a 4-foot horizontal leg that passes into the tank of ice. The heat pipe portion above ground is insulated until it enters the tank. The instrumentation cable is seen at the right, as it leaves the pipe.

FIGURE III-9

80 FOOT LONG HEAT PIPE
WHICH TRANSPORTED 1 KW OVER
75 FEET AT ROOM TEMPERATURE

dynaTherm CORPORATION

structure would be required. The closed artery is a "composite" type wick which allows the capillary pumping and the liquid transport to be independently optimized. That is, large capillary pumping heads can be attained without incurring excessive viscous flow losses.

In the highway application, the wick structure must be capable of satisfying the transport requirements over as much as a 50-foot vertical column. The large vertical distance imposes the most stringent requirements on a down-piping heat transport system. Because of the large vertical distances involved, the capillary pumping needed to meet the transport requirements is relatively small compared to that needed to support the vertical liquid column.

Theoretically, for a given working fluid, the capillary pumping capability of an arterial heat pipe is inversely proportional to the effective capillary pumping radius. That is,

$$P_p = \frac{2\sigma \cos\theta}{r_p} \qquad \text{III-1}$$

where r_p = Capillary pumping radius

σ = Surface tension of working fluid

θ = Contact angle between liquid and wick material

The elevation head is:

$$P_e = \rho g h \qquad \text{III-2}$$

where g = Gravitational constant

h = Height of liquid column

ρ = Density of liquid column

Combining Equations III-1 and III-2 yields the height of the liquid column as a function of capillary pore radius for a given working fluid. Figure III-10 is a plot of the pumping height of an arterial wick as a function of the capillary pumping radius for several working fluids.

Conventional wick materials and fluids can support a liquid column of approximately 1 to 2 feet. As part of the investigation to develop a down-pumping heat transporter, measurements were made with various small-pore size materials to determine their static pumping heads. Electroformed nickel screen in sizes of 500, 1000, 1500, and 2000 mesh and a polycarbonate film (Nuclepore) in sizes of 1.0 and 8.0 microns were tested using water and methanol fluids.

The test setup is shown in Figure III-11. Gas pressure is applied to the wick material which is immersed in the working fluid. The static elevation head (i.e., capillary pumping head) is that pressure at which the menisci break. The menisci are located in the pores of the material at the liquid and the gas interface. The break point is evidenced by bubble evaluation from the material specimen. Test results are presented in Table III-1. The one micron pore size is capable of supporting a 20-foot elevation with methanol as the working fluid. This corresponds to a predicted elevation head of 25 feet with ammonia as the working fluid.

The experimental data indicates that the effective pumping radius is generally larger than the theoretical pumping radius. For example, the theoretical capillary pumping radius of one micron Nuclepore is equal to the pore radius; i.e., $r_p = 2 \times 10^{-5}$ inch. This corresponds to a pumping height of approximately 36 feet for methanol. However, the experimental data indicates a pumping height of approximately 20 feet for methanol with one micron Nuclepore. This corresponds to an effective capillary

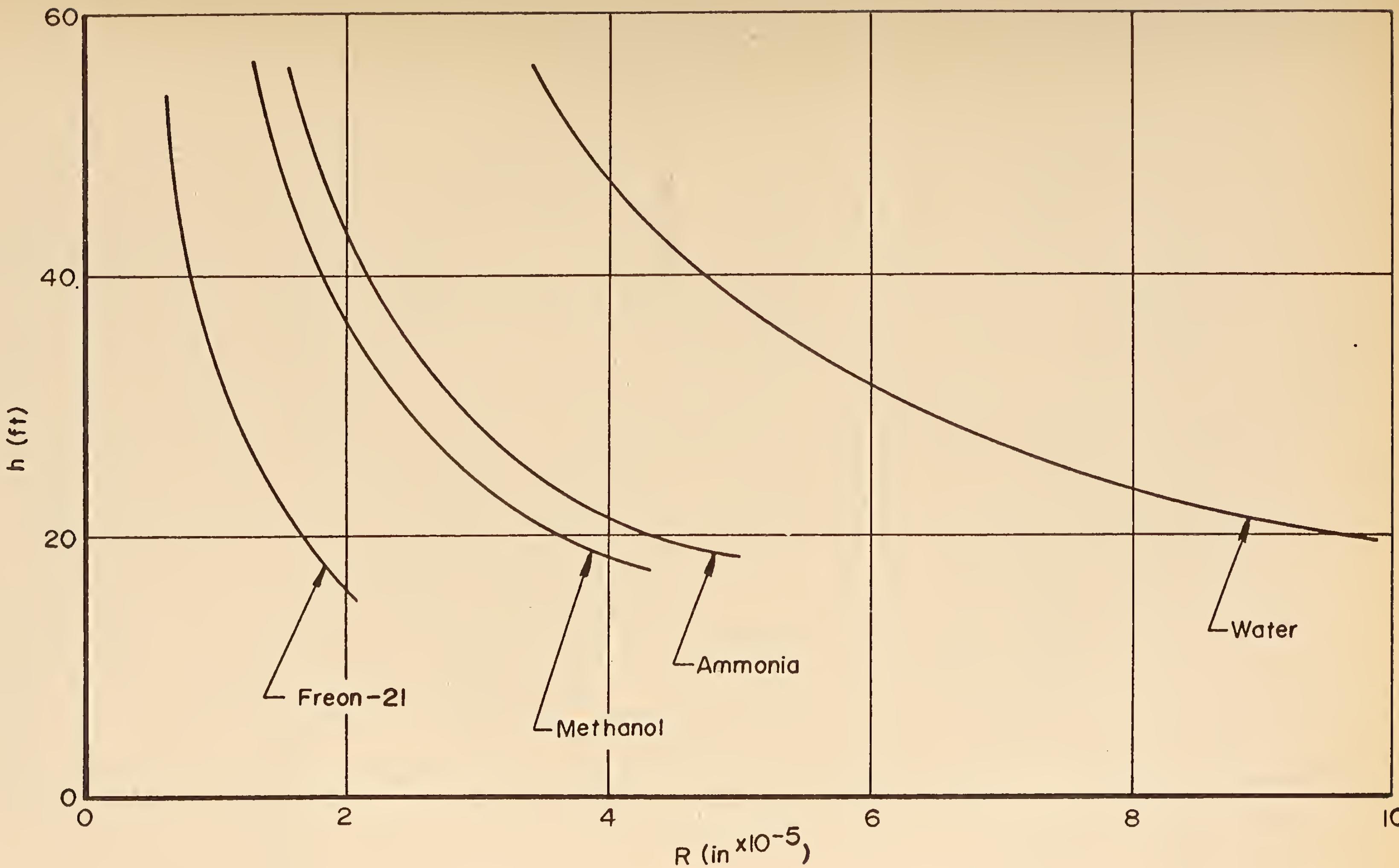


FIGURE III-10

PUMPING HEIGHT OF AN ARTERIAL HEAT PIPE AS A FUNCTION OF CAPILLARY PUMPING RADIUS FOR VARIOUS POTENTIAL WORKING FLUIDS

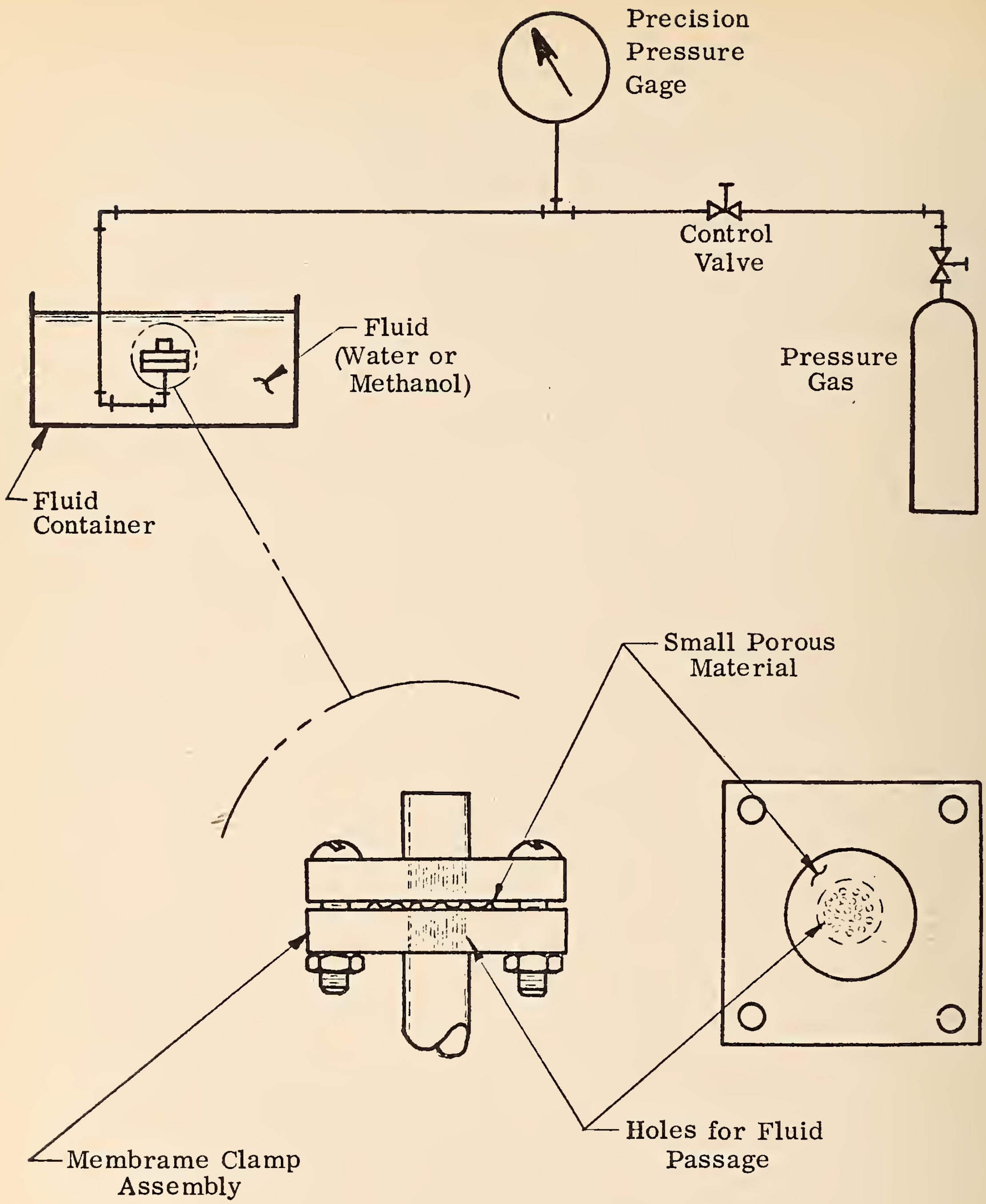


FIGURE III-11

EXPERIMENTAL SETUP TO MEASURE STATIC PRESSURE HEAD OF SMALL PORE MATERIAL

Nominal Pore Size	Elevation Head (Inches)	
	Water	Methanol
500 Mesh Screen	23.6	--
1000 Mesh Screen	44.5	21.2
1500 Mesh Screen	86.0	--
2000 Mesh Screen	96.0	42.0
8 Micron Membrane	77.6	45.3
1 Micron Membrane	--	245.0

TABLE III-1

MEASURED STATIC ELEVATION HEADS

pumping radius of 3.6×10^{-5} inch, almost twice as large as the theoretical value. It is likely that this discrepancy is due to nonuniform pore sizes in the Nuclepore membrane. The capillary pumping radii determined from the static elevation head will correspond to the largest pore size, whereas theoretical capillary pumping radii are based on an average pore size. Since the Nuclepore membrane is available in smaller pore sizes, wick materials do exist which are capable of supporting sufficiently large elevation heads.

There are additional considerations when evaluating the feasibility of a down-pumping heat pipe. First of all, there must be a mechanism for priming the artery in the event that it opens. An artery could be opened and deprimed during operation because of excessive heat loads or because of the presence of a gas bubble in the artery. Once the artery is opened, it can only support a liquid column of less than one inch and down pumping would be impossible. Secondly, the Nuclepore material must be incorporated into a practical arterial wick structure. In summary, more development is needed before it will be feasible to store summer heat in the earth storage reservoir using down-pumping heat pipes.

IV. SYSTEM TESTING AND RESULTS

A. Description of Fairbank Test Facility

The test facility, located at Fairbank Highway Research Station, is designed to investigate the variables associated with removing snow and ice from pavement surfaces by thermal methods. The general site arrangement is shown in Figure IV-1. The site is an outdoor open space, away from buildings, and covers an area of about 4000 ft^2. As shown in Figure IV-1, there are three 12-foot by 24-foot concrete test slabs:

- Unheated Control Slab
- Electrically Heated Slab
- Earth Heat Pipe Slab

Also shown is the service building which contains the flaked ice machine and weighing equipment. The control trailer contains the data acquisition system and the power control console. The locations of the three 40-foot deep instrumentation poles are also shown in Figure IV-1. Photographs of the test site are shown in Figure IV-2.

All of the test slabs are 9 inches thick following the trend in modern highway construction. The Control Slab is unheated and serves as a test control for the Electrical and Earth Slabs. Both the Electrical and Earth Slabs contain heat pipes charged with ammonia. In the Electrical Slab, each heat pipe terminates outside the slab in a short down leg. This is wrapped with an electrical heater which can be controlled at selected power levels from the instrumentation trailer. In the Earth Slab, each heat pipe extends beyond the slab boundaries and then into the earth to depths of either 30 or 40 feet. All of the heat pipes run parallel to the 12-foot dimension and have a 1.25-inch cover of concrete over them. The in-pavement portions of the heat pipes are made

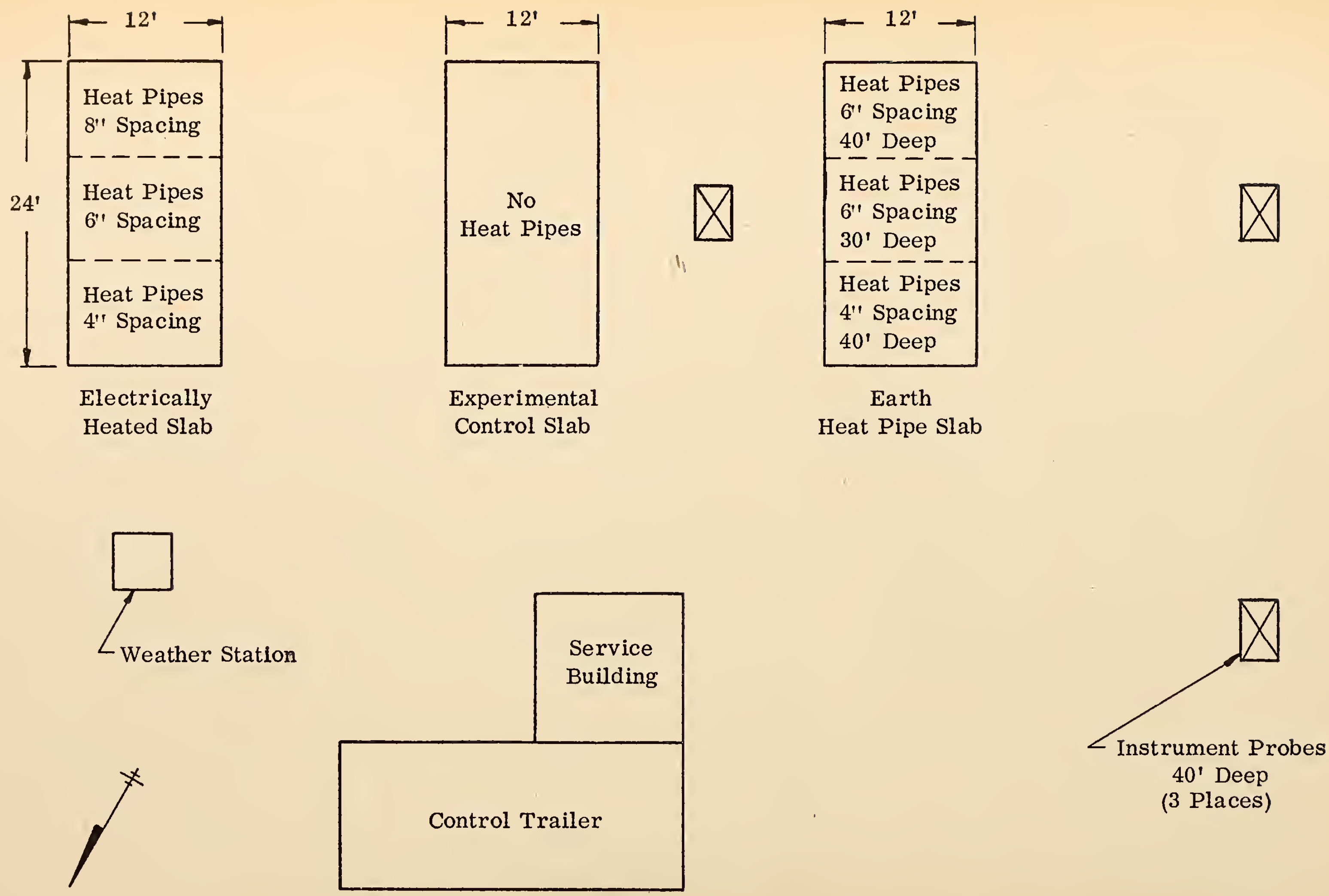
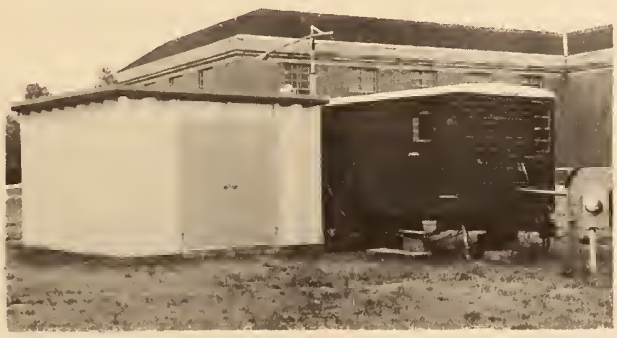


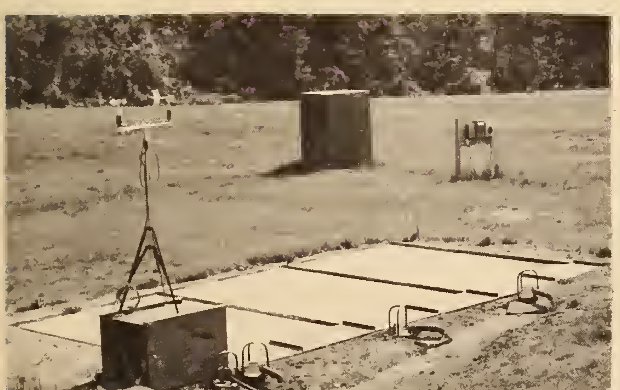
FIGURE IV-1

GENERAL SITE ARRANGEMENT

General View of Site. Earth Heat Pipe Slab in foreground, Experimental Control Slab between it and Electrically Heated Slab in background.

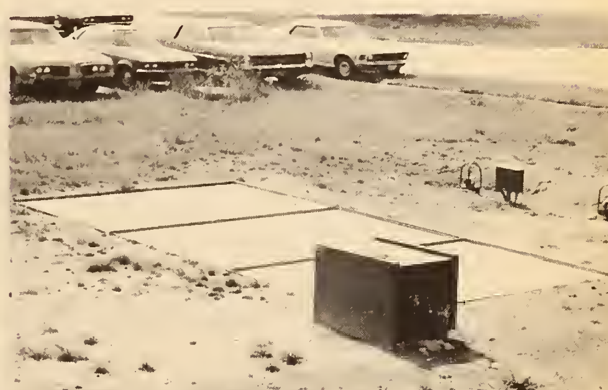


Butler Building and Trailer



Electrically Heated Slab

Note Weather Instrumentation Mast on top of cable termination box.



Earth Heat Pipe Slab

FIGURE IV-2

SITE ARRANGEMENT

of 1/2-inch nominal black iron pipe and the down legs from one inch nominal black iron pipe.

Each of the heated slabs is divided into three 12-foot by 8-foot test panels which are suitably dammed and individually drained so that separate melt tests can be conducted. The melt water from each test panel collects in a separate sump and is removed by means of a pressure-actuated pump. This permits investigating the effects of pipe spacing, pipe depth, and surface heat flux on melt-rate under various ambient conditions.

The Electrical Slab consists of test panels A, B, and C. Panel A contains 12 heat pipes configured as 2-pronged forks -- making a total of 24 embedded pipes on a spacing of 4 inches. Panel B contains 16 heat pipes on a 6-inch spacing, and Panel C contains 12 heat pipes on an 8-inch spacing. Each heat pipe terminates in a short down leg outside the slab and has its own 1000-watt heater. Effective pipe spacing can be varied in increments by shutting appropriate heaters off.

The Earth Slab consists of test panels D, E, and F. Panel D contains 12 heat pipes configured as 2-pronged forks identical to Panel A of the Electrical Slab. Panel E contains 16 pipes on a spacing of 6 inches with the in-earth portion of the pipe extending to a depth of 30 feet. Panel F is identical to Panel E except that the pipes extend to a depth of 40 feet. The heat pipes extend from both sides of the Earth Slab in an alternating sequence and enter the earth on a pattern of 3-foot centers.

All test slabs were heavily instrumented with thermocouples. There are 1200 active instrumentation channels and numerous unconnected thermocouples which can be used as spares for special experiments. The Earth Slab has 600 assigned channels, the Electrical Slab 440, and the remaining channels are assigned to the Control Slab and the Instrumentation Poles. Figure IV-3 illustrates a typical instrumentation elevation. The

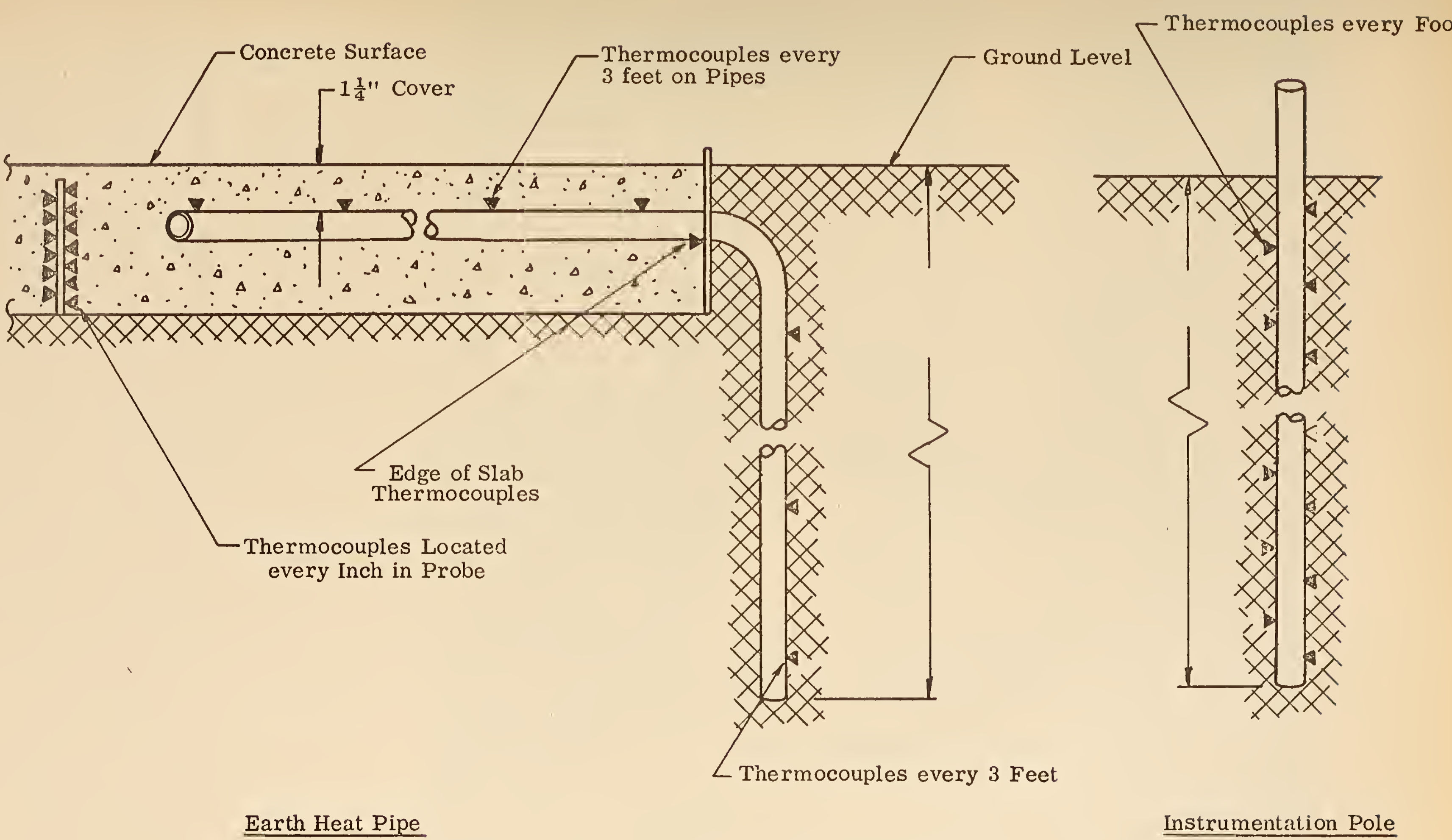


FIGURE IV-3

ELEVATION SCHEMATIC OF INSTRUMENTATION

thermocouples are a heavy-duty copper constantan type and were securely fastened in the proper location prior to the pour.

In addition to thermocouples, each heater circuit of the heat pipes in the Electrical Slab contains a Hall-Effect watt transducer. These transducers are calibrated to measure power and have a millivolt output so that they can be read out by the same instrumentation that reads out thermocouples.

There are three Instrumentation Poles, used to monitor earth temperature, installed vertically in the ground to a depth of 40 feet. Thermocouples are attached to each pole at intervals of one foot. One pole is located adjacent to the Control Slab, one is located in the midst of the earth heat pipes, and one is 60 feet away from the Earth Slab. Thus, the effect of the thermal energy drain from the earth by the heat pipes could be investigated.

The flaked ice machine and its storage bin and the beam scale are located in the service building. Figure IV-4 is a photograph of this equipment. This capability was provided so that melt-rate testing could be conducted in the absence of snow.

Figure IV-5 shows the Data Acquisition System. The system is capable of reading 1200 channels. By using a keyboard, any combination of channels can be selected for readout and can be recorded on paper tape or on magnetic tape.

Test site weather instruments were provided to measure ambient temperature, relative humidity, wind velocity, and solar flux. The anemometer, mounted on top of the Electrical Slab instrument housing, and the pyranometer, mounted on top of the Butler Building, can be seen in the photographs in Figure IV-2. Relative humidity and ambient temperature measurements were taken at the Weather Station (Figure IV-1) using a psychrometer and a thermocouple.

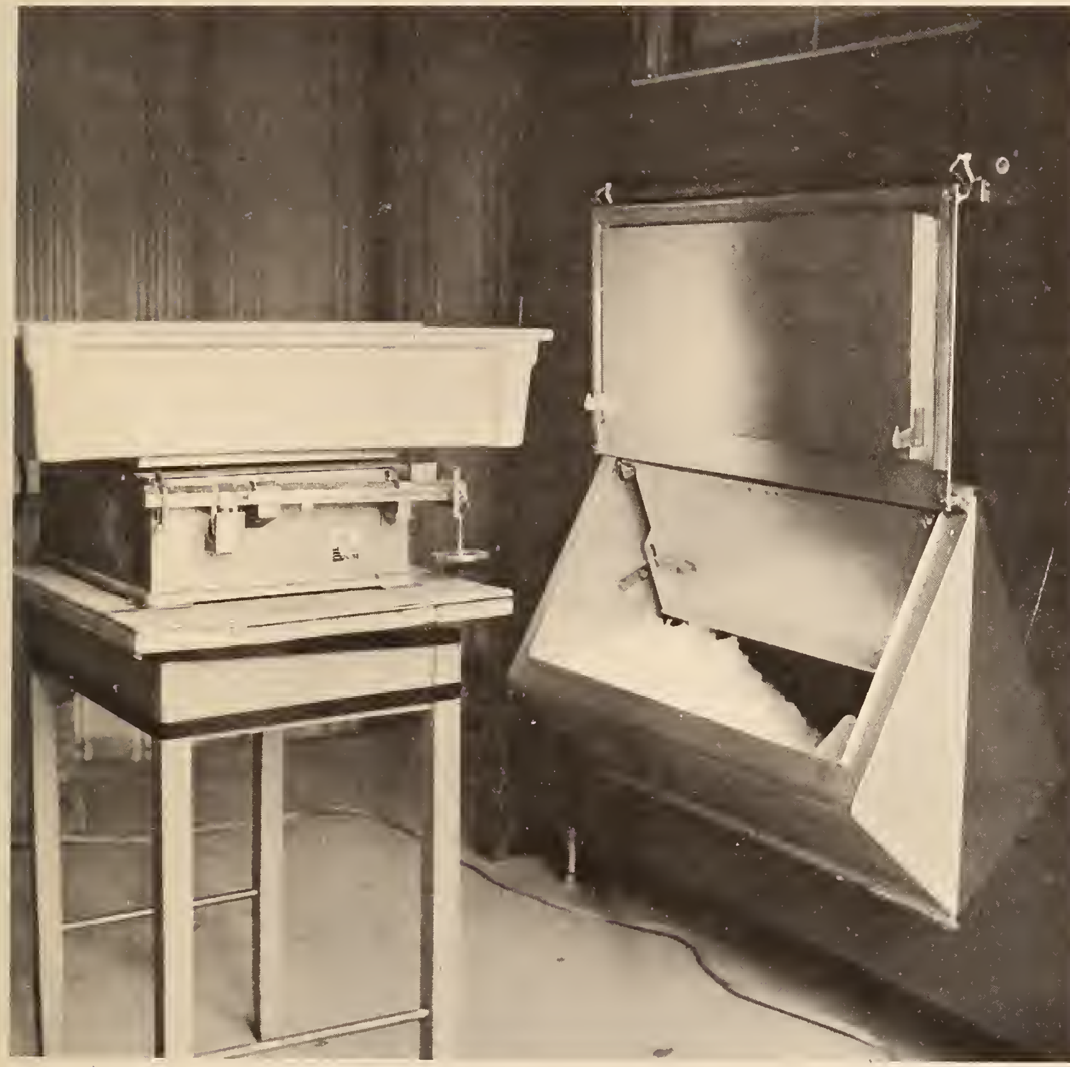


FIGURE IV-4

FLAKE ICE MACHINE AND WEIGHING APPARATUS

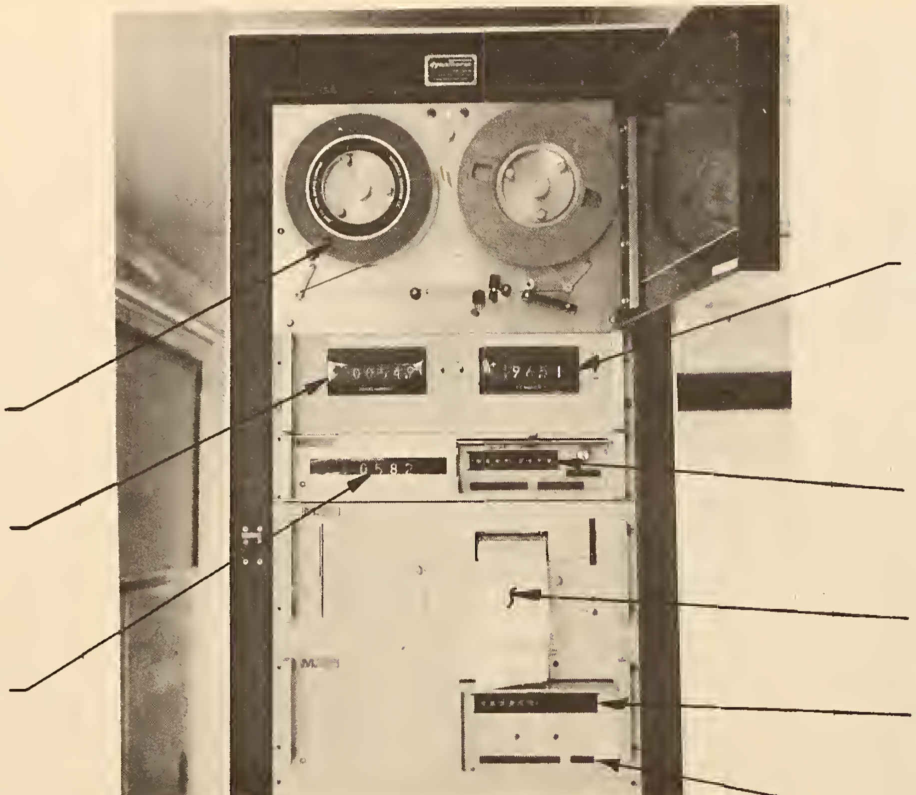


FIGURE IV-5

DATA ACQUISITION SYSTEM PANEL CONTROLS

B. Construction of Fairbank Test Facility

1. Test Hardware Fabrication

After an extensive program of component testing, a final design for the test facility at Fairbank Highway Research Station (FHRS) was formulated. The general procedure followed in the fabrication of the Electrical Slab Test Panel assemblies was as follows:

- Welding of heat pipe assemblies
- Bake-out, outgas, and leak check of pipes
- Installation of thermocouples on pipes
- Attachment of electric heaters and power lines
- Filling with NH_3
- Placement of pipes in frames

Several photographs were taken which illustrate various stages of fabrication.

Figure IV-6 shows the helium mass spectrometer leak checking of forked heat pipes which were later placed in the Electrical Slab. Figure IV-7 illustrates the method of thermocouple attachment which was used on all heat pipes. Component testing had shown that it was necessary to eatablish both a good thermal contact and a strong physical bond between the thermocouple and the heat pipe. Figure IV-8 shows the test panel frames for the Electrical Slab. These frames provided dimensional reference for the placement of heat pipes as well as forms for the concrete test slabs. Figure IV-9 shows a nearly completed electrical slab test panel assembly.

The same general procedure was followed during the fabrication of the Earth Slab heat pipes. The heat pipes were bent in the field and then were placed

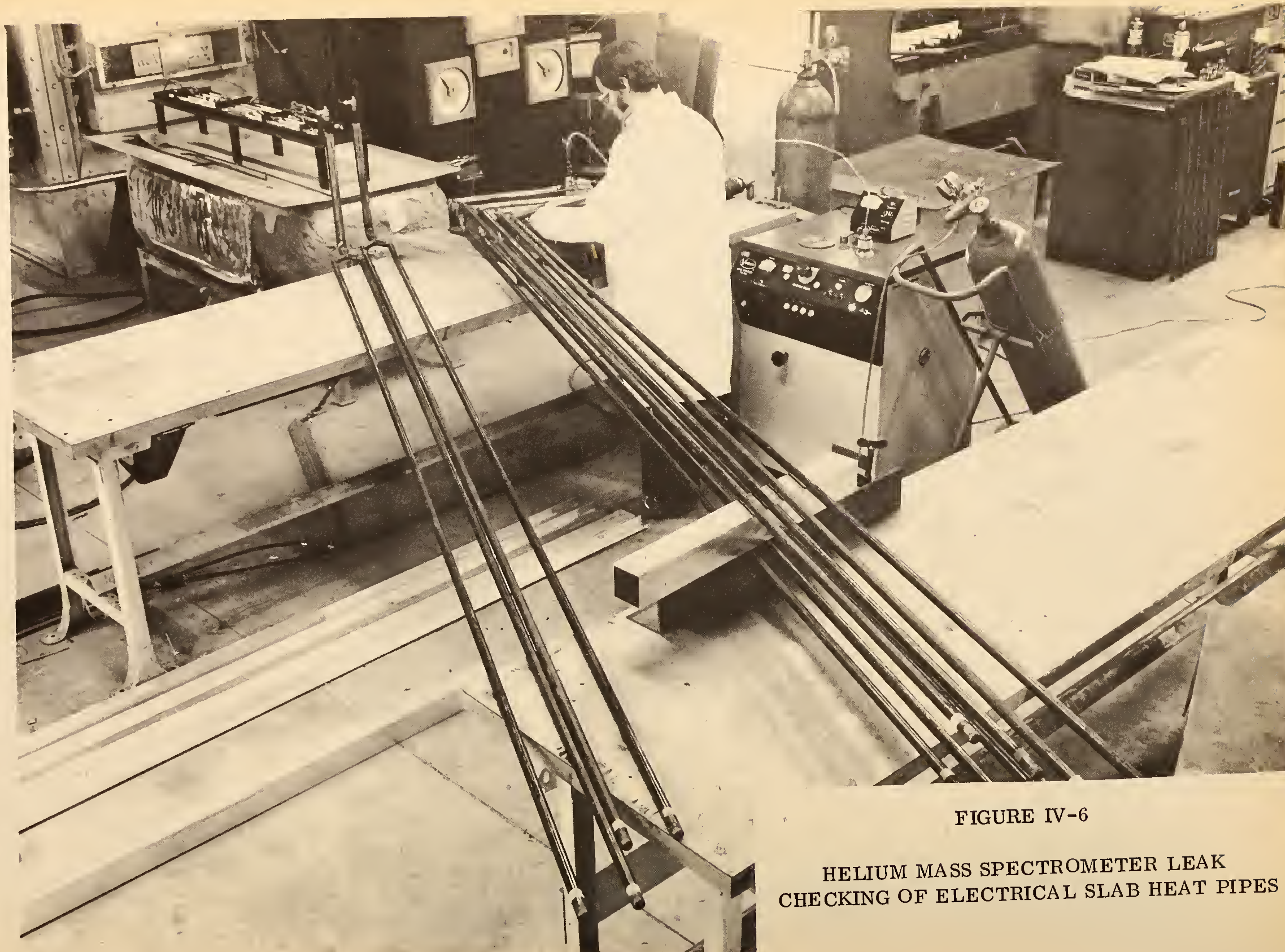


FIGURE IV-6

HELIUM MASS SPECTROMETER LEAK
CHECKING OF ELECTRICAL SLAB HEAT PIPES

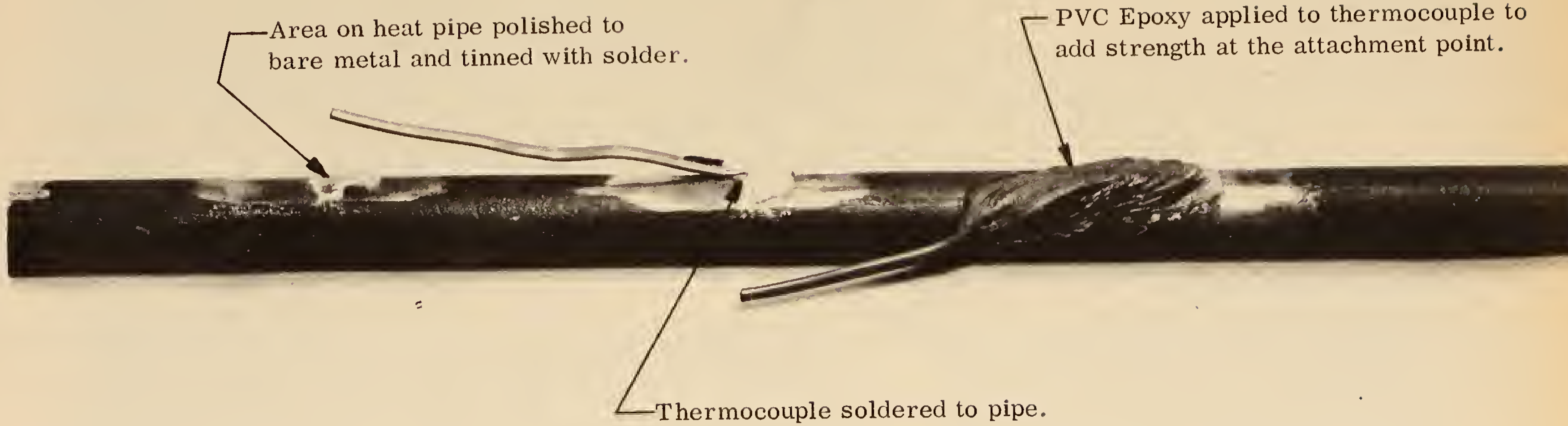


FIGURE IV-7

SPECIMEN TO ILLUSTRATE METHOD OF THERMOCOUPLE ATTACHMENT

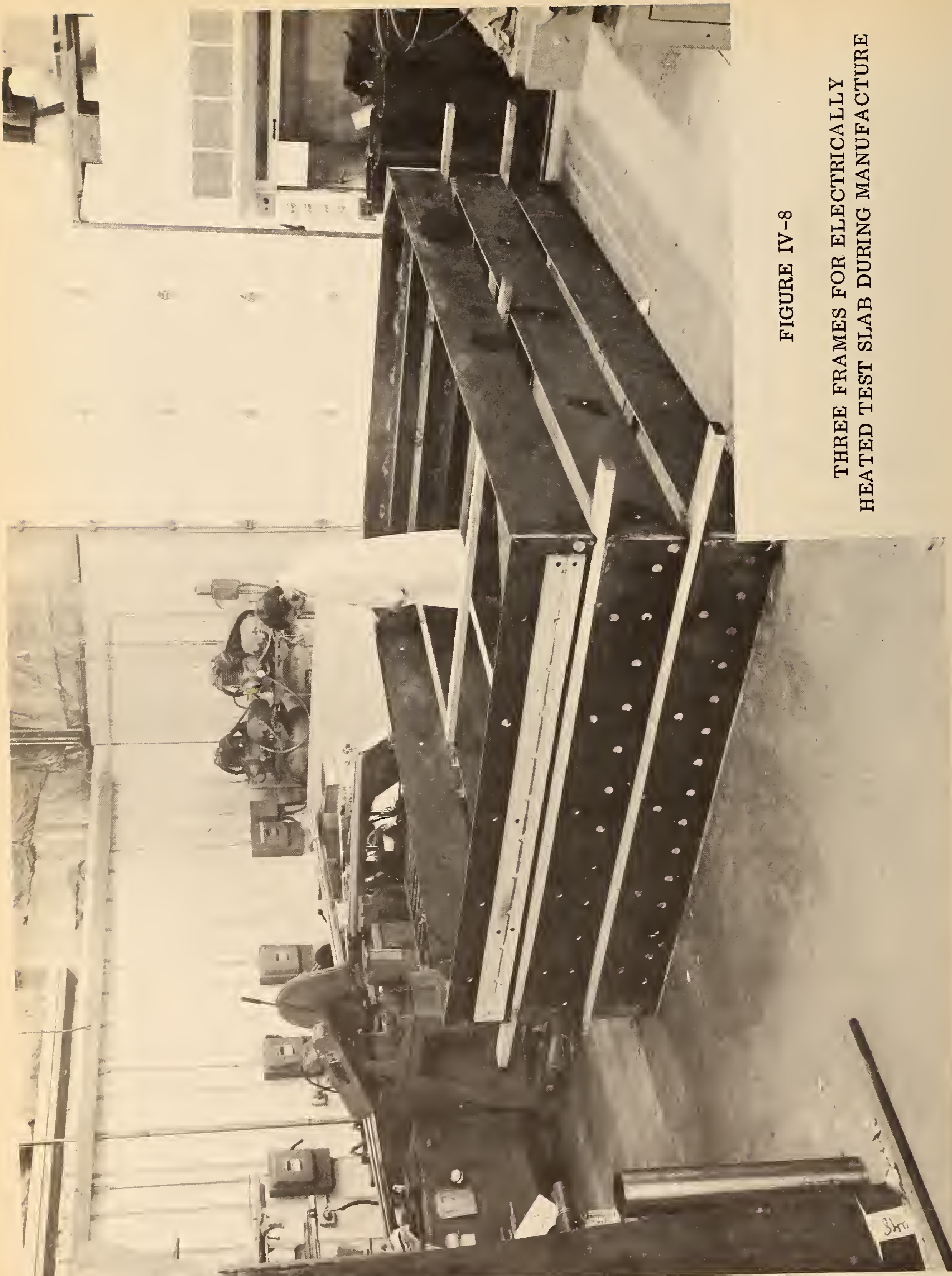


FIGURE IV-8

THREE FRAMES FOR ELECTRICALLY
HEATED TEST SLAB DURING MANUFACTURE

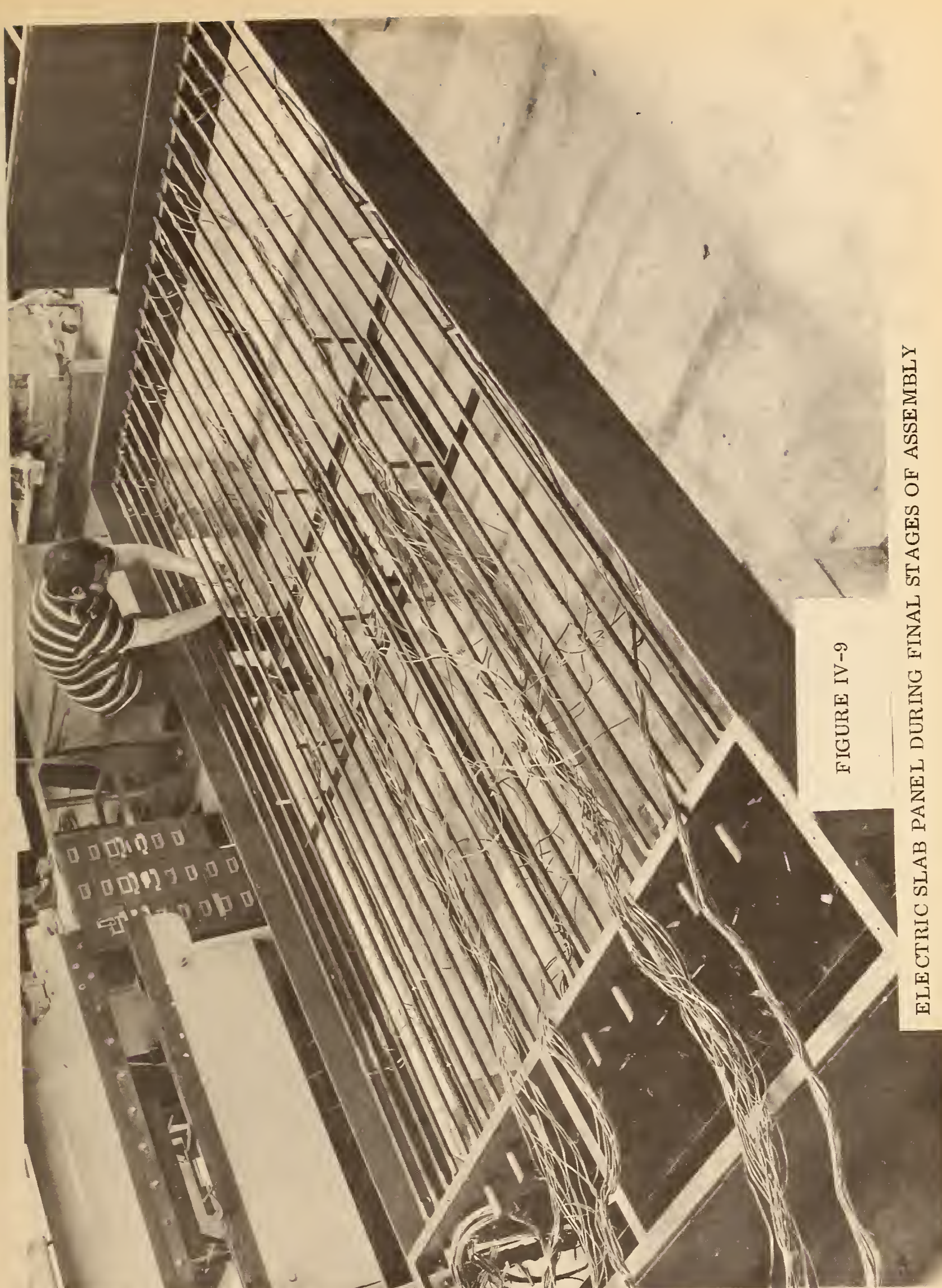


FIGURE IV-9

ELECTRIC SLAB PANEL DURING FINAL STAGES OF ASSEMBLY

in the test panel frames. Figure IV-10 is a photograph of the field-bent Earth Slab heat pipes taken during drilling of the holes for the vertical legs of the earth heat pipes.

In addition to the test panel frames and the heat pipes, Dynatherm designed and manufactured the sumps used to collect the melt water from each panel and the instrument housings (located adjacent to the Earth and Electrical Slabs) which contained the terminals for all thermocouples and switching devices.

2. Test Site Construction

The construction of the test site at FHRS was initiated in June, 1972. During the month of June, both the Electrical and Control Slabs were poured, and several of the holes for the earth heat pipes were drilled. However, in late June, Hurricane Agnes struck and test site construction had to be suspended until August, 1972. During August, the drilling of the holes was completed, the earth heat pipes were installed, and the Earth Slab was poured.

Exploratory drilling at the test site revealed the presence of a gneissic rock formation beginning 13 to 15 feet below ground level. Therefore, it was necessary to employ a rock drilling rig to bore the holes for the three instrumentation poles and the 44 earth heat pipes. The photograph in Figure IV-11 shows the drilling in progress. The powdered gneissic rock from the holes was collected. After the earth heat pipes were placed, it was mixed with water to form a mud slurry and then pumped into the holes as backfill.

Figure IV-12 shows the three test panel sections of the Electrical Slab which had been bolted, leveled, and anchored on top of nine inches of tamped

FIGURE IV-10

PART OF THE FIELD-BENT EARTH HEAT PIPES

FIGURE IV-11

DRILLING OF EARTH HEAT PIPE HOLES

The fog effect is powdered gneissic rock. Note the 21-A Substrate beneath the Slab Frames.

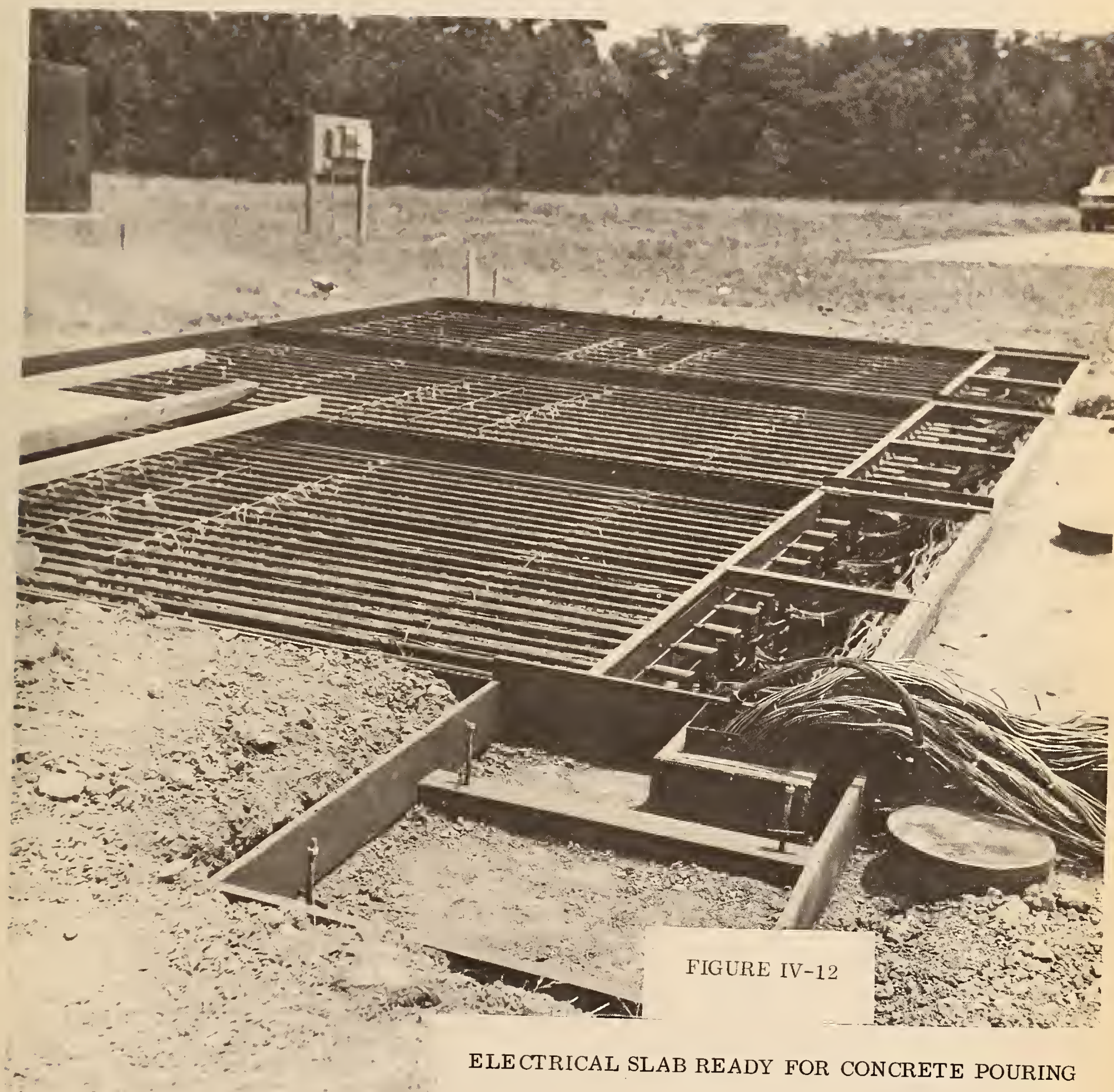


FIGURE IV-12

ELECTRICAL SLAB READY FOR CONCRETE POURING

gravel in preparation for the pouring of the concrete. The sumps for collecting the melt water can be seen in front of the electrical through.

In constructing the test slabs, modern highway construction practices were followed. The slabs are poured on subbases of Type 21A stabilized aggregate which is layered and tamped. The concrete in the slabs in Class AA PPC in accordance with FP-69, Section 501. Specifically, the mixture had the following constituents:

- 564 pounds - Type I Portland cement
- 1185 pounds - Sand in sizes of 100 to number 4
- 2000 pounds - AASHO-M43, size number 57 stone
- 37 gallons - Water
- 2 ounces - Protex entraining agent

Figure IV-13 shows the concrete being poured in the final test panel on the Earth Slab. After each slab was poured, it was covered with a plastic sheet for the duration of the cure period.

Insulation was applied to the horizontal portions of the earth heat pipes that extend from the bore holes to the edges of the slab. This prevented earth heat from being dissipated before it reached the concrete slab. Following this operation, the excavated area around the Earth Slab was backfilled and leveled. Ditches were dug along each of the three slabs to convey the runoff water which was discharged by the sump pumps to an area beyond the instrumentation trailer. The site was graded to prevent the accumulation of surface water near the test slabs. This stage of the test site construction was completed in August 1972.

FIGURE IV-13

POURING EARTH HEAT PIPE SLAB

The portions of the Heat Pipes in the foreground were insulated prior to backfill to grade. These pipes extend 30 feet into the ground. The vertical stub pipe at left is the top of a 40-foot long instrumentation pole.

Further work needed to make the Fairbank Test Site operational continued through January, 1973. The tasks performed included the following:

- A 5-inch thick concrete slab was poured on which the Butler Building was erected.
- A hard-pipe water supply line was laid to the Butler Building and connected to the flaked ice machine.
- The Instrumentation Trailer was moved into place, and the Data Acquisition System and an instrument cabinet were installed. The cabinet had been equipped with three variable transformers for regulating the power to the Electrical Panels and an electrical distribution box containing circuit breakers for all test electrical power.
- Space heaters were installed in the trailer and in the Butler Building.
- Pumps and control switches were mounted at the sumps, and antifreeze heaters were installed in the sumps and on drain and water lines.
- Hall-Effect Watt Transducers were wired across the controlled power lines of the Electrical Slab Heaters.
- Interconnecting cables for electrical power were run from the circuit breaker panel to the Electrical Slab Heaters, sumps, and water and drain line antifreeze heaters. Power cables were also wired to the Butler Building and the trailer.

- Twelve hundred thermocouple and Watt Transducer Channel hook-ups were made to the crossbar switching units. Also, signal cables were run to the Data Acquisition System.

- Weather instrumentation was installed.

- System check-out and calibration was performed to assure that the system was ready for testing.

C. Winter Testing During 1972 -1973

Winter testing was conducted at the Fairbank Highway Research Station during the months of February and March of 1973. During this period, the air temperatures were somewhat milder than those normally experienced. In addition, this was one of the few winters on record during which no snow fell.

Due to the lack of natural snowfall, all melt tests were conducted with the use of flaked ice. Tests were conducted both during the day and during the night on the Earth, Control, and Electrical Slabs. Tests were also conducted with continuous and intermittent power applied to the Electrical Panels.

Table IV-1 shows a summary of the climatic conditions experienced during the melt tests. Table IV-2 indicates the test panels utilized during a particular experiment and their applied power.

During all melt tests the Data Acquisition System recorded heat pipe temperatures, a network of temperatures within the concrete slab, ground temperature profiles, and heater input on the Electrical Slab heat pipes. A detailed report of the analysis of this data, as well as the data obtained during the next winter, is given in Section V. In general, sufficient data was obtained to permit the analysis to proceed.

Test No.	Date	Test Mode	Ambient Temperature (^{o}F)	Wind Velocity (mph)	Sky Cover	Relative Humidity (%)
1001	2/12/73	Flake Ice	23.5-28.5	0-5	Clear	29-40
1002	2/14/73	Flake Ice	21.0-33.0	0-5	Cloudy	85-92
1003	2/17/73	Flake Ice	21.0-26.0	10-15	Clear	30-44
1004	2/19/73	Flake Ice	31.0-42.0	0	Clear - Partly Cloudy	36-56
1005	2/21/73	Flake Ice	27.0-41.0	2-4	Cloudy - Clear	83-92
1006	2/22/73	Flake Ice	24.0-31.0	7-20	Clear - Partly Cloudy	58-60
1007	2/23/73	Flake Ice	24.0-27.0	0-5	Partly Cloudy - Cloudy	56-70
1008	3/20/73	Flake Ice	30.5-34.5	0-5	Partly Cloudy - Cloudy	59-78
1009	3/22/73- 3/23/73	Flake Ice	28.0-37.0	0-5	Partly Cloudy - Cloudy	59-64

TABLE IV-1

SUMMARY OF TEST CONDITIONS -
WINTER OF 1972-1973

Test No.	Applied Power (Watts/Ft^2)						
	Electrically Heated Slab			Experimental Control Slab	Earth Heat Pipe Slab		
	Panel A 4" Spacing	Panel B 6" Spacing	Panel C 8" Spacing		Panel D 4" Spacing 40' Deep	Panel E 6" Spacing 30' Deep	Panel F 6" Spacing 40' Deep
1001	N/A*	N/A	N/A	0.0	N/A	N/A	Earth
1002	N/A	N/A	N/A	0.0	N/A	N/A	Earth
1003	N/A	N/A	11.7	0.0	N/A	N/A	N/A
1004	N/A	11.4	N/A	0.0	N/A	N/A	N/A
1005	N/A	N/A	N/A	0.0	N/A	Earth	Earth
1006	11.1	11.1	N/A	0.0	N/A	N/A	N/A
1007	N/A	0.0**	N/A	N/A	N/A	Earth	Earth
1008	0.0	0.0-41.8	0.0-32.3	0.0	N/A	Earth	Earth
1009	0.0-29.1	N/A	N/A	0.0	N/A	Earth	Earth

*N/A means panel not utilized during testing.
**Electrical power to this panel shutoff 15 hours prior to testing.

TABLE IV-2

SUMMARY OF APPLIED POWER TO TEST PANELS - WINTER OF 1972-1973

D. Winter Testing During 1973-1974

The first and largest snowfall of the Winter occurred in mid-December. This snowfall reached blizzard proportions with abnormally high winds, low temperatures, and with approximately 9 inches of snow falling in a period of 24 hours. In the latter part of December and throughout the month of January, exceptionally mild weather persisted. For the month of January, the ambient temperatures averaged 6°F above the norm for the period.

During the month of February, the temperatures hovered around the norm for the period. On the 8th of the month, the second and last major snowfall of the winter occurred. During this last snowfall, approximately 6 inches of snow fell in a 24-hour period. The weather for the month of March was again milder than usual with average temperatures being 3°F above the norm. The two substantial snowfalls which occurred during the winter of 1973-1974 provided excellent opportunities to study the behavior of a heat pipe deicing system during adverse weather conditions. Extremely hazardous driving conditions prevailed on the roads during both snowfalls.

A broad spectrum of tests were conducted during the Winter of 1973-1974 in order to validate a thermal model of the heat pipe pavement deicing system. Melt tests were conducted with natural snow and with artificial flaked ice on the Earth, Control, and Electrical Slabs. In addition, a dry test was conducted on all three slabs to facilitate the analysis of the performance of the heat pipe system. Table IV-3 is a summary of the climatic conditions encountered during the different test modes.

Comparable tests were conducted while varying such parameters as heat pipe spacing, electrical power inputs, heat pipe depth, and ambient conditions, so that the effects of each of these factors on system performance could be thus evaluated.

Test No.	Date	Test Mode	Ambient Temperature (^{o}F)	Wind Velocity (mph)	Sky Cover (Tenths)	Relative Humidity (%)
2001	12/17-12/18/73	Snow	17.0-30.0	0-27	0.0-1.0	47-100
2002	12/21/73	Snow	26.0-30.0	2-22	0.9-1.0	63-100
2003	1/9/74	Snow/Sleet	34.0	0-8	1.0	92-100
2004	1/18/74	Flake Ice	29.0-35.0	0-12	1.0	43-60
2005	2/6/74	Flake Ice	21.0-29.0	0-4	0.1-0.8	44-71
2006	2/8/74	Snow	22.0-25.0	0-10	1.0	75-89
2007	2/25/74	Snow	31.0-33.0	0-23	0.8-1.0	68-100
2008	3/24/74	Dry	28.0-31.5	0-16	0.0	31-34

TABLE IV-3

SUMMARY OF TEST CONDITIONS -
Winter of 1973-1974

Table IV-4 summarizes the applied power to each of the pertinent test panels during a particular test. The Experimental Control Slab does not contain heating elements and, therefore, benefits only from the heat input of its environment, as is the case with the normal highway pavements. This is also true of the Electrical Slab test panels which were not activated during some of the tests.

The results of an in-depth analysis of the test data are reported in Section V. This section will contain a qualitatively oriented discussion of the testing and the results. A brief description of each test follows:

1. Test 2001

This test provided an excellent opportunity to study the performance of a heat pipe pavement deicing system during blizzard conditions. A total of 9.5 inches of snow was deposited on the ground, with almost 9 inches falling in a 24-hour period. Temperatures dipped to a low of 17 $^{\circ}$F and winds gusted up to 27 miles per hour.

Several photographs were taken to show the condition of the test panels during the experiment. Figure IV-14 shows the condition of Panels E and F of the Earth Heat Pipe Slab. These panels have heat pipes spaced on 6-inch centerlines and running to depths of 30 and 40 feet, respectively. At this time, approximately 5.5 inches of snow had fallen. As indicated by the photograph, the panels utilizing earth heat pipes were capable of melting most of the incident snowfall. In addition to the incident snowfall, a considerable amount of drifting occurred and is indicated in Figure IV-14 along the sides of the melt area. The ridges of snow shown in this figure occur in areas between the heat pipes.

	Applied Power (Watts/Ft^2)						
	Electrically Heated Slab			Experimental Control Slab	Earth Heat Pipe Slab		
Test No.	Panel A 4" Spacing	Panel B 6" Spacing	Panel C 8" Spacing		Panel D 4" Spacing 40' Deep	Panel E 6" Spacing 30' Deep	Panel F 6" Spacing 40' Deep
2001	0-30.0	0.0	0.0	0.0	Earth	Earth	Earth
2002	9.9	0.0	20.0	0.0	Earth	Earth	Earth
2003	9.9	0.0	20.0	0.0	Earth	Earth	Earth
2004	9.8	N/A*	N/A	0.0	N/A	Earth	N/A
2005	N/A	10.0	N/A	0.0	N/A	Earth	Earth
2006	0-30.0	10.0	10.0	0.0	Earth	Earth	Earth
2007	0.0	10.0	10.0	0.0	Earth	Earth	Earth
2008	5.7	5.1-9.8	7.1	0.0	N/A	Earth	Earth

*N/A means panel not utilized during testing.

TABLE IV-4

SUMMARY OF APPLIED POWER TO TEST PANELS - WINTER OF 1973-1974

FIGURE IV-14

EARTH SLAB, PANELS E & F

Test 2001, December 17, 1973, 01:00

Figure IV-15 shows the condition of the same panels at the conclusion of the testing. During this interval, four more inches of snow fell and, additionally, a large amount of drifting had occurred. Because the elevation of the Earth Slab was depressed due to melting of snow, a large quantity of snow drifted on to the test panels. The majority of all incident snow was melted by the earth heat pipes, as indicated in Figure IV-15. The ice that does appear on the slabs was formed when melt water wicked up in the remaining snow cover and refroze. However, this ice did not adhere to the concrete surface and was easily dislodged.

Figure IV-16 shows the condition, at the end of testing, of the Electrical Slab Test Panel A, which has heat pipes spaced on 4-inch centerlines. This test panel had 30 watts/ft^2 applied to it after it had a surface covering of approximately 5 inches of snow. This amount of power was more than sufficient to melt all the snow on the panel.

2. Test 2002

This test coincided with the second major snowfall of the season and occurred a few days after that of Test 2001. The previous day, Panel A and Panel C of the Electrical Slab were activated with applied powers of 10 and 20 watts/ft^2, respectively. The snow accumulation amounted to one inch, temperatures ranged from 26 to 30°F, and winds gusted up to 22 mph. Panel C, with 20 watts/ft^2, remained clear throughout the experiment while Panel A, with 10 watts/ft^2, had small ridges of slush/ice between the pipes after extensive drifting occurred. Panels E and F, on the Earth Slab, also had

FIGURE IV-15

EARTH SLAB, PANELS E & F
Test 2001, December 18, 1973, 16:00

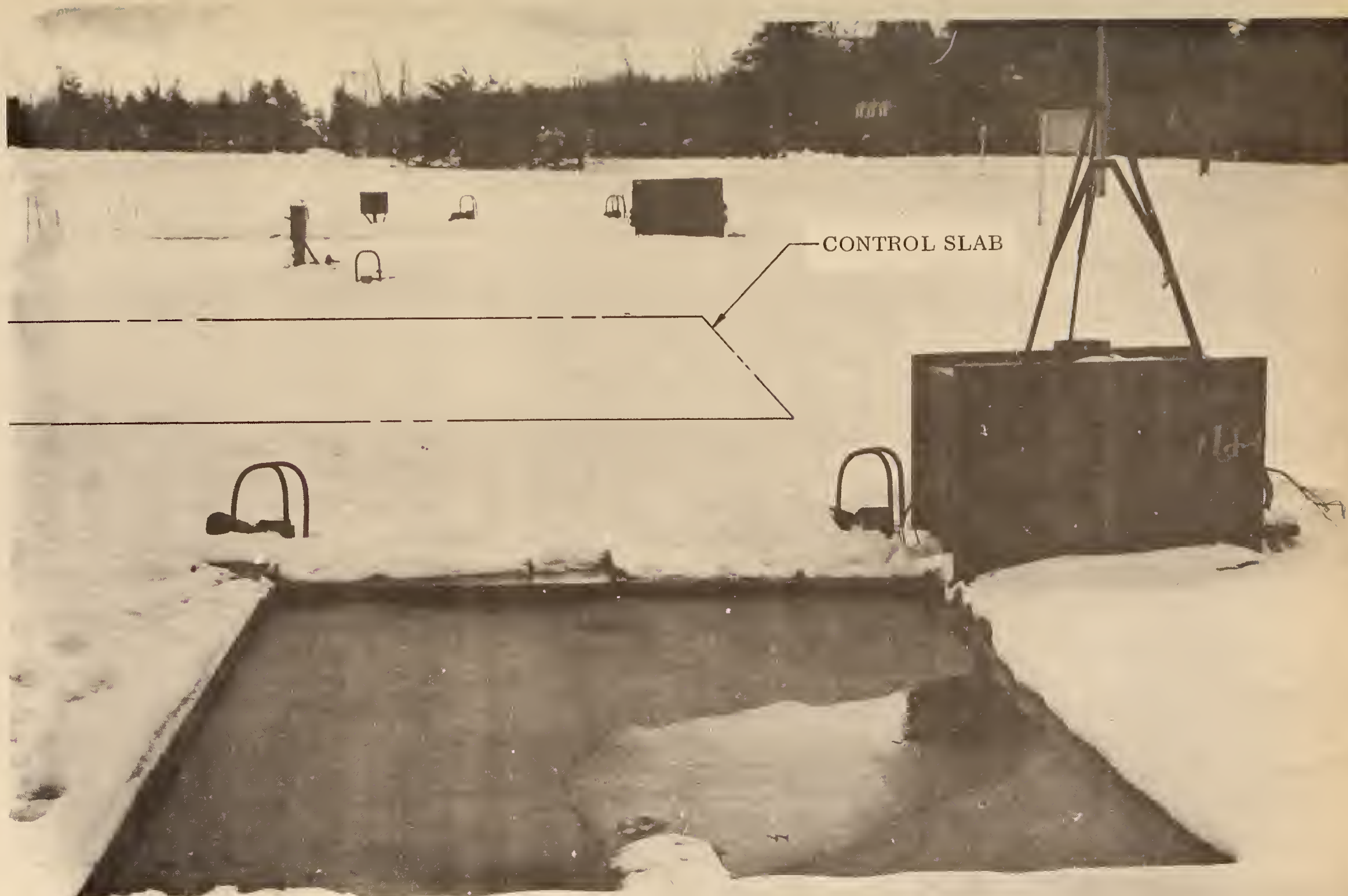


FIGURE IV-16

ELECTRICALLY HEATED SLAB, PANEL A
Test 2001, December 18, 1973, 16:00

ridges of slush and ice mixture between the heat pipes but remained clear over most of their surface area. These ridges were formed when snow drifted onto the slab and melt water wicked up into the snow and formed a thin layer of ice on top of the resulting slush.

3. Test 2003

A small amount of snow fell during the early hours of the morning and changed to sleet and rain before dawn. The total accumulation of the snow-slush-ice mixture on the ground was approximately one inch. Panels A and C with applied powers of 10 watts/ft^2 and 20 watts/ft^2, respectevely, showed no evidence of snow or ice accumulation. Panel B, which was not activated, and the Experimental Control Slab had a layer of the slush-like mixture. Panel E of the Earth Slab was completely clear and Panel F was clear except for one patch which had an area of approximately 15 square feet. It was noted in several tests that this portion of Panel F exhibited a low performance, indicating a malfunctioning of the heat pipes. This malfunctioning is attributable to either gas generation or liquid blockage in the heat pipes.

4. Test 2004

In this test, flaked ice was applied to Panel A of the Electrical Slab (which had an applied power of 10 watts/ft^2) to the Experimental Control Slab, and to Panel E of the Earth Slab. The experiment was conducted at night to eliminate the effect of solar radiation and to obtain the most stable climatic conditions. Temperature and wind variations at night at the test site were found to be minimal.

Initially, melting was observed on the Control Slab as well as the heat pipe slabs. However, as the temperature of the Control Slab decreased, this water froze and a highly adhesive interface formed between the concrete and ice. This is analogous to the surface condition observed on roads after freezing rain or a thaw-freeze cycle of a snow covering. This did not occur on the Electrically Heated Panel or on the Earth Heat Pipe Panel. The interface between the ice and concrete remained fluid throughout the experiment.

5. <u>Test 2005</u>

For this experiment, flaked ice was again applied to the Earth, Electrical, and Control Slabs. This time, however, flaked ice was applied to Panel B of the Electrical Slab, which had an applied power of 10 watts/ft^2, and to Panels E and F on the Earth Slab. The climatic conditions were more severe for this test than the previous one, as the ambient temperature dipped to 21°F and the sky was mostly clear, thus promoting increased radiative losses.

The melt rates observed on Panels B and E corresponded closely, while Panel F had a somewhat lower melt rate. This was in part due to the portion of Panel F which has a condenser blockage problem. On the Control Slab, no melting occurred.

6. <u>Test 2006</u>

This test was conducted during the second major snowfall of the season. It snowed 6 inches in a period of 12 hours while the air temperature hovered between 22°F and 25°F. Panels B and C on the Electrical Slab had

10 watts/ft^2 applied continuously and Panel A was activated with 30 watts/ft^2 about 6 hours after the snowfall started.

Figures IV-17 and IV-18 show the condition of the Earth and Electrical Slabs, respectively, after it had been snowing for approximately 8 hours. At this time, the ambient temperature was 24°F, the wind varied from 0 to 10 mph and there was a snow cover of about 3 3/4 inches on the surrounding ground. It can be observed in Figure IV-17 that Panels E and F on the Earth Slab were capable of completely melting this amount of incident snowfall over most of their surface area. The portions which do have a snow cover are in regions where the heat pipes are experiencing a larger than usual resistance between the earth source and pavement sink. Panels B and C, shown in Figure IV-18, were capable of melting all incident snowfall with a continuously applied power of 10 watts/ft^2. Panel A, which had 30 watts/ft^2 applied 2 hours before this photograph was taken, had a noticably diminished snow cover by this time.

Figures IV-19 and IV-20 are photographs taken in the same location three hours later. The snow accumulation on the ground at this time was 5 1/4 inches; therefore, the average snowfall rate during this period was 1/2 inch per hour. The areas of the Earth Slab Panels, which were clear in Figure IV-17, are still clear in Figure IV-19 indicating that Panels E and F were capable of melting this rate of snowfall under the ambient conditions experienced during testing. On the Electrical Slab, Panels B and C remained clear during this interval, and Panel A melted the remaining snow cover in addition to the snow that fell during the interval. It was approximately 4 1/2 hours

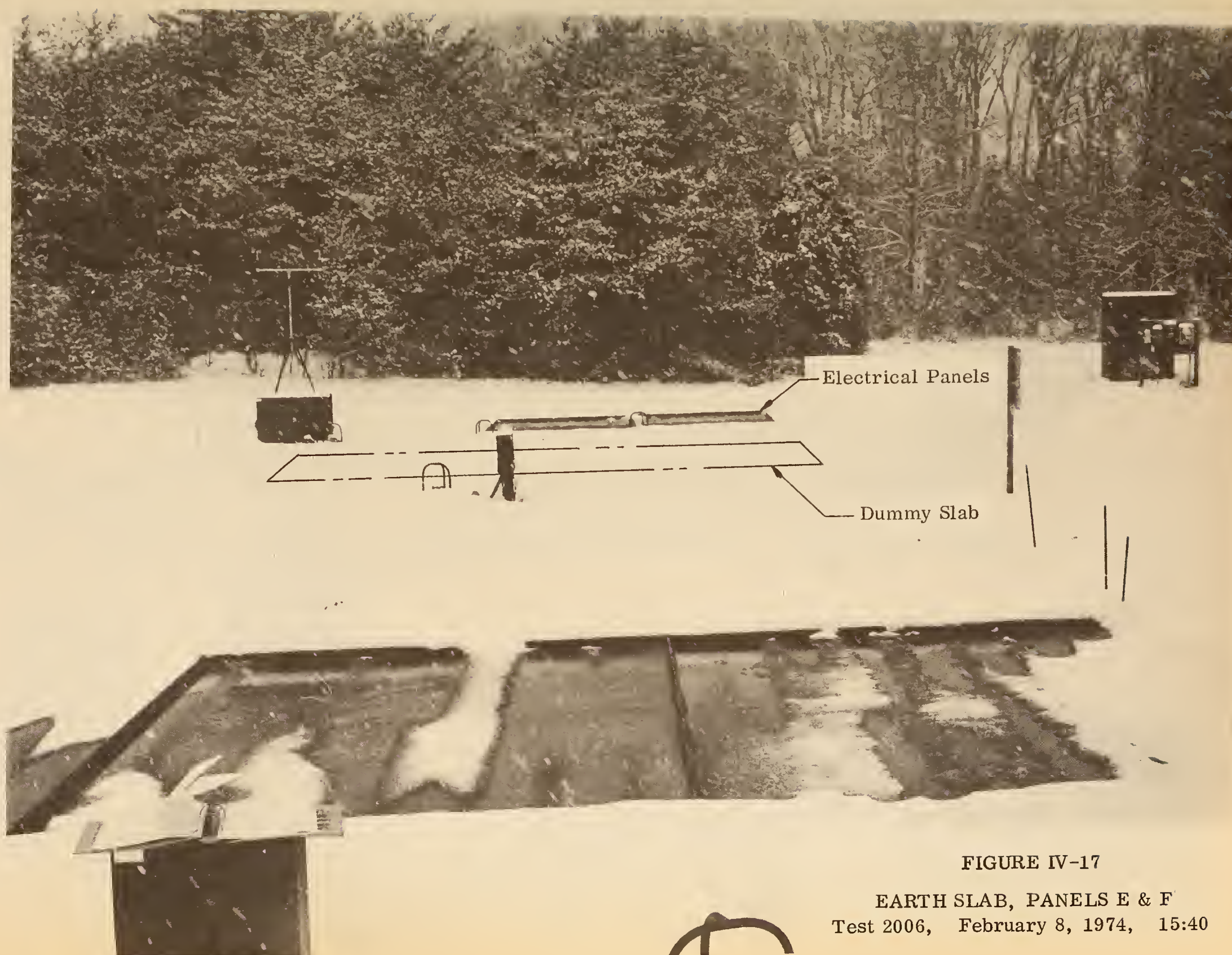


FIGURE IV-17

EARTH SLAB, PANELS E & F
Test 2006, February 8, 1974, 15:40

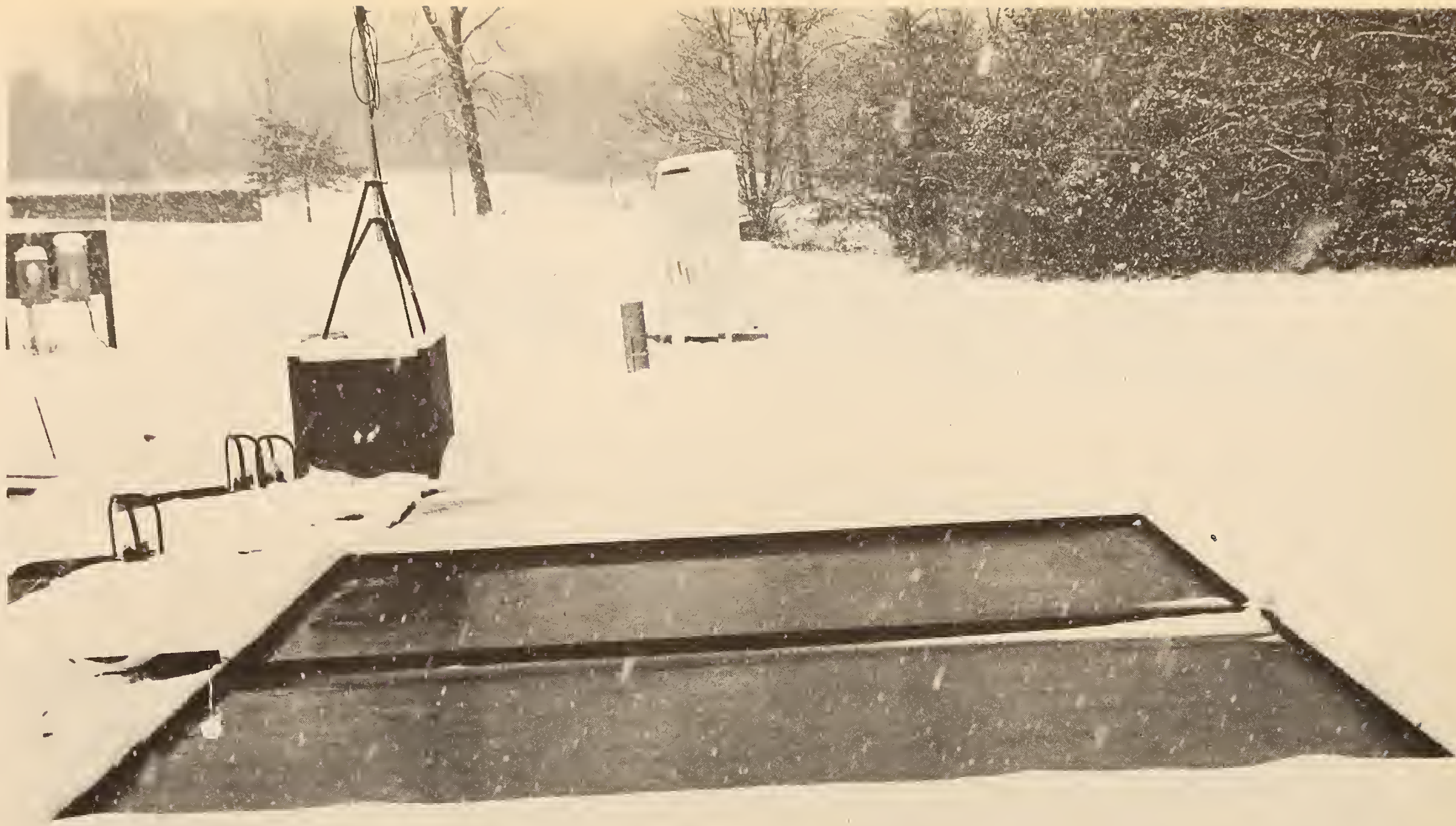


FIGURE IV-18

ELECTRICAL SLAB, PANELS A, B, & C
Test 2006, February 8, 1974, 15:40

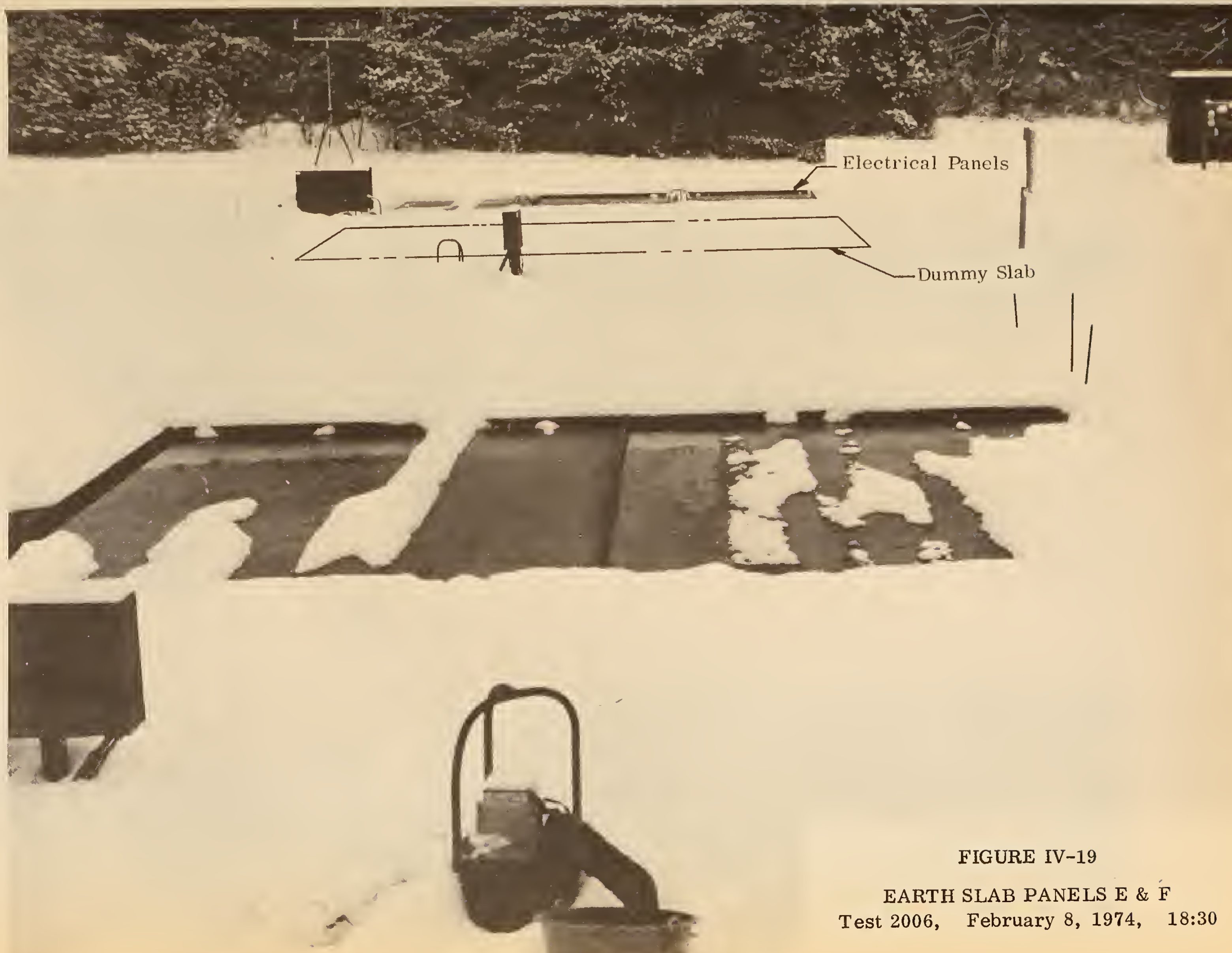


FIGURE IV-19

EARTH SLAB PANELS E & F
Test 2006, February 8, 1974, 18:30

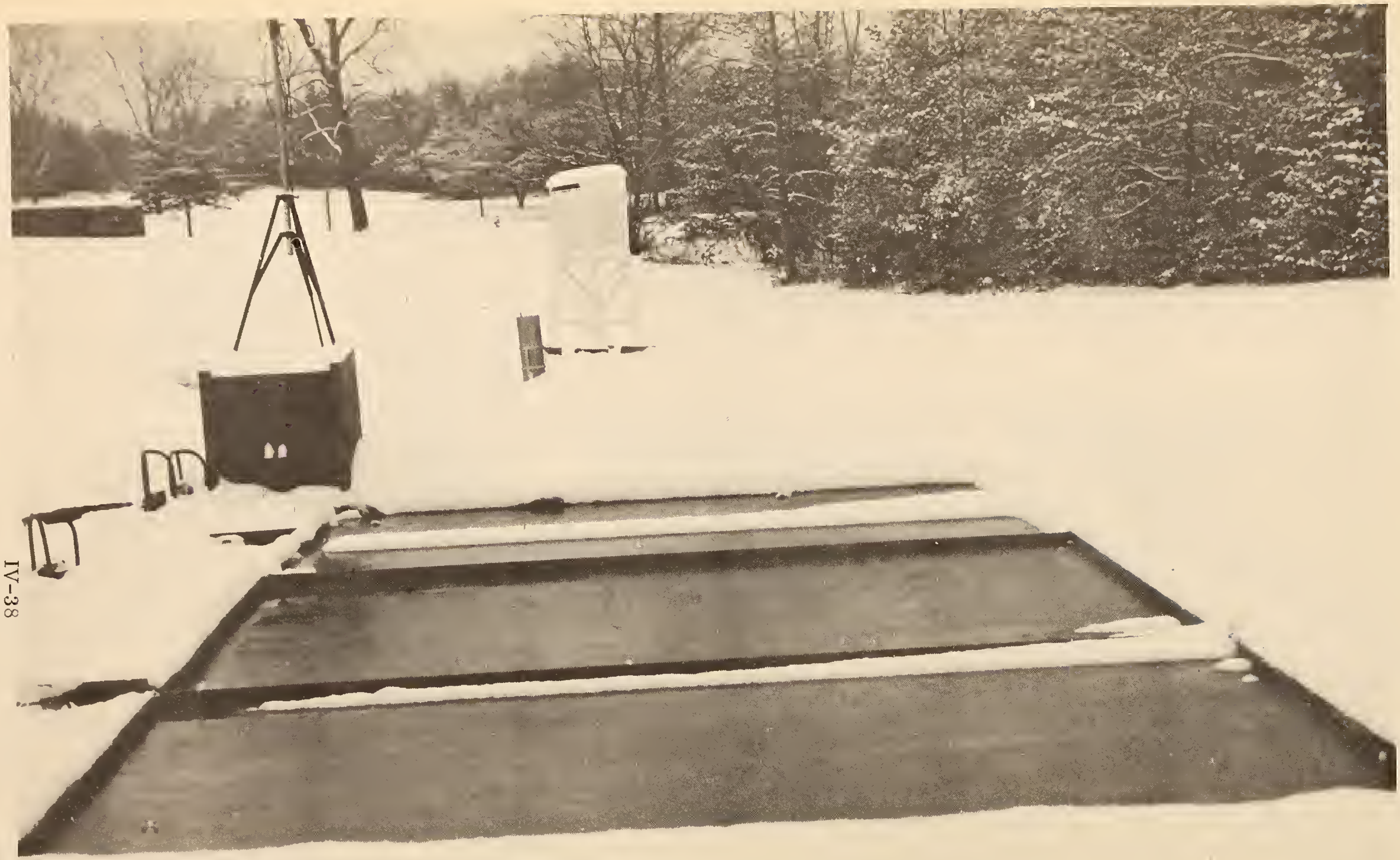


FIGURE IV-20

ELECTRICAL PANELS A, B, & C
Test 2006, February 8, 1974, 18:30

after 30 watts/ft^2 was applied to Panel A that it attained a surface condition similar to Panels B and C which had been operating continuously at 10 watts/ft^2.

7. Test 2007

This test was conducted during a snowfall. However, since the accumulation was negligible, this test did not yield any usable data or observation.

8. Test 2008

This test was conducted while the surface of the test panels was dry. This provided an experiment which could be analyzed without regard to the heat losses incurred by melting and evaporation.

The Data Acquisition system accumulated data continuously during this experiment and recorded the following parameters on an hourly cycle:

- Heat pipe temperatures
- A network of temperatures in the concrete slabs
- Heater input on the Electrical Slab Test Panels
- Ground temperature profiles

Also recorded were the climatic conditions and the surface temperature of the test panels.

V. ANALYSIS OF SYSTEM BEHAVIOR AND PERFORMANCE

A. Computer Averaging

A computer program was developed which has the ability to read and utilize the data tapes created during the tests conducted at the Fairbank Test Site. This program was designed to average thermocouples grouped according to their location which is the first step to analysis of the system behavior. By appropriate selection of thermocouple groups, this program, for an earth heat pipe slab, provides average heat pipe temperatures as a function of depth in the ground and position in the slab, average grid temperature variations for above and in-between heat pipes, and average slab temperature along the depth probe. For an electrical slab, the average heat pipe flux is also obtainable. Since these averages are available as a function of time, the program results in an indication of the system's transient behavior.

During the initial stages in the development of this program, numerous problems were encountered in attempts to read the original tapes. Most of these problems resulted from the use of concurrent end-of-life markings during tape production. However, these problems were resolved by alterations in both the job control language and the Fortran program.

Included within the program is a mechanism which automatically eliminates faulty instrumentation by disregarding temperatures outside the range from 20°F to 90°F. Some additional human judgements were made in specific cases to exclude faulty thermocouples that were within this temperature range but were clearly unreliable.

A typical computer printout is shown in Table V-1, for Panel F during Ice Melt Test 2005. An explanation of the location of all thermocouple groups is given in Table V-2. Several indications of the system's behavior are illustrated in this printout. The

DATE	RUN	TIME
20674	2005	110

GROUP ID	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25	26	27	28		
AVERAGING QUANTITY	53.6	51.9	51.7	51.3	51.3	51.3	51.2	55.8	53.6	51.2
	49.1	51.9	52.0	52.9	50.6	33.8	35.0	42.6	33.1	36.9
	33.6	33.8	34.2	37.5	33.3	33.6	39.7	45.7		

DATE	RUN	TIME
20674	2005	305

GROUP ID	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20
	21	22	23	24	25	26	27	28		
AVERAGING QUANTITY	53.3	51.7	51.1	51.1	51.1	51.1	51.0	55.7	53.8	51.2
	49.0	51.8	52.0	53.0	50.4	33.2	34.6	42.9	32.6	36.2
	33.6	33.8	33.9	37.4	33.2	33.5	39.5	38.2		

TABLE V-1

TYPICAL COMPUTER PRINTOUT

DATE	RUN	TIME
20674	2005	300

GROUP ID

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28		

AVERAGING QUANTITY

53.0	51.4	50.8	50.8	50.8	50.7	50.8	55.5	53.3	51.0
49.2	51.8	51.9	52.6	50.1	32.8	34.2	42.8	31.8	35.6
33.5	33.6	33.7	38.0	33.1	33.3	40.6	37.8		

DATE	RUN	TIME
20674	2005	400

GROUP ID

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28		

AVERAGING QUANTITY

52.7	51.4	50.8	50.8	50.9	50.9	50.8	55.5	52.0	51.0
49.2	51.7	51.9	52.7	50.2	32.4	34.2	42.8	31.5	35.5
33.5	33.5	33.6	38.1	33.0	33.3	39.7	37.6		

TABLE V-1 (Cont'd)

TYPICAL COMPUTER PRINTOUT

DATE	RUN	TIME
20674	2005	500

GROUP ID	AVERAGING QUANTITY
1	53.0
11	49.2
21	33.5
2	51.1
12	51.8
22	33.6
3	51.0
13	51.9
23	33.7
4	51.0
14	52.8
24	38.2
5	51.0
15	50.3
25	33.0
6	51.0
16	32.4
26	33.4
7	50.8
17	34.2
27	39.7
8	55.6
18	41.8
28	37.4
9	52.2
19	31.3
10	51.1
20	35.5

DATE	RUN	TIME
20674	2005	600

GROUP ID	AVERAGING QUANTITY
1	52.9
11	49.2
21	33.7
2	51.0
12	52.0
22	34.0
3	50.9
13	52.1
23	33.9
4	50.9
14	52.9
24	38.6
5	51.0
15	50.2
25	33.2
6	51.0
16	32.2
26	33.5
7	50.8
17	34.2
27	40.8
8	55.7
18	42.3
28	37.2
9	52.5
19	31.2
10	51.2
20	35.4

TABLE V-1 (Cont'd)

TYPICAL COMPUTER PRINTOUT

GROUP No.	GROUP LOCATION
1	North Pipes, 39.5 feet deep
2	North Pipes, 33.5 feet deep
3	North Pipes, 27.5 feet deep
4	North Pipes, 15.5 feet deep
5	North Pipes, 9.5 feet deep
6	North Pipes, 3.5 feet deep
7	North Pipes, 30 inches North of North edge of slab
8	South Pipes, 39.5 feet deep
9	South Pipes, 33.5 feet deep
10	South Pipes, 27.5 feet deep
11	South Pipes, 15.5 feet deep
12	South Pipes, 9.5 feet deep
13	South Pipes, 3.5 feet deep
14	South Pipes, 30 inches South of South edge of slab
15	North Pipes, 3 inches South of North edge of slab
16	North Pipes, 91 inches South of North edge of slab
17	North Pipes, 141 inches South of North edge of slab
18	South Pipes, 3 inches North of South edge of slab
19	South Pipes, 91 inches North of South edge of slab
20	South Pipes, 141 inches North of South edge of slab
21	Grid, 12 inches North of center, between pipes
22	Grid, on center
23	Grid, 12 inches South of center, between pipes
24	Grid, 12 inches North of center, above North pipes
25	Grid, 12 inches North of center, above South pipes
26	Grid, 12 inches South of center, above North pipes
27	Grid, 12 inches South of center, above South pipes
28	Depth Probe, Located at center of panel

Note: North Pipes are those with vertical legs buried on the North side of Panel (left hand side of drawing # 018-1000-004A). South pipes are those with vertical legs buried on the South side of Panel (on right hand side of drawing # 018-1000-004A).

TABLE V-2

THERMOCOUPLE GROUP SPECIFICATION FOR PANEL F

time variation of Group 28, the average depth probe temperature, signifies the transient adjustment of the concrete to the addition of ice. Also, the thermocouple groups located on the portion of the heat pipes within the concrete can be used as an indication of condenser blockage. The use of Groups 15, 16, and 17, and Groups 28, 19, and 20 in generating Figures V-1 and V-2 clearly evidence the extent of condenser blockage during this test. In Figures V-3 and V-4, the extent of condenser blockage in the right and left heat pipes during Test 1007 (conducted on February 23, 1973) is shown. The increase in condenser blockage during the period between these tests indicates that the heat pipes are generating noncondensible gas.

Although the thermocouple groups do not contain faulty instrumentation, this program's results must be used with reservation on the earth heat pipe slabs because of condenser blockage. Consequently, the heat pipe temperatures used during later stages of the test evaluation were obtained by hand computations, since judgments on an individual basis were required for each pipe.

B. Thermal Performance of Dry Slabs

The mathematical model which has been developed can only be used as an analytical device if it is validated by experimental results. The thermal behavior of a concrete surface exposed to ambient is dependent upon certain system parameters. These include the thermal losses, ground heat inputs, pavement conductivity, pavement thermal capacitance, concrete-pipe resistance, and heat pipe spacing. Since some of these parameters are not applicable to all experimental conditions, sequential application of the model for various conditions can result in the definition of all these parameters. This is the method by which the mathematical model was validated.

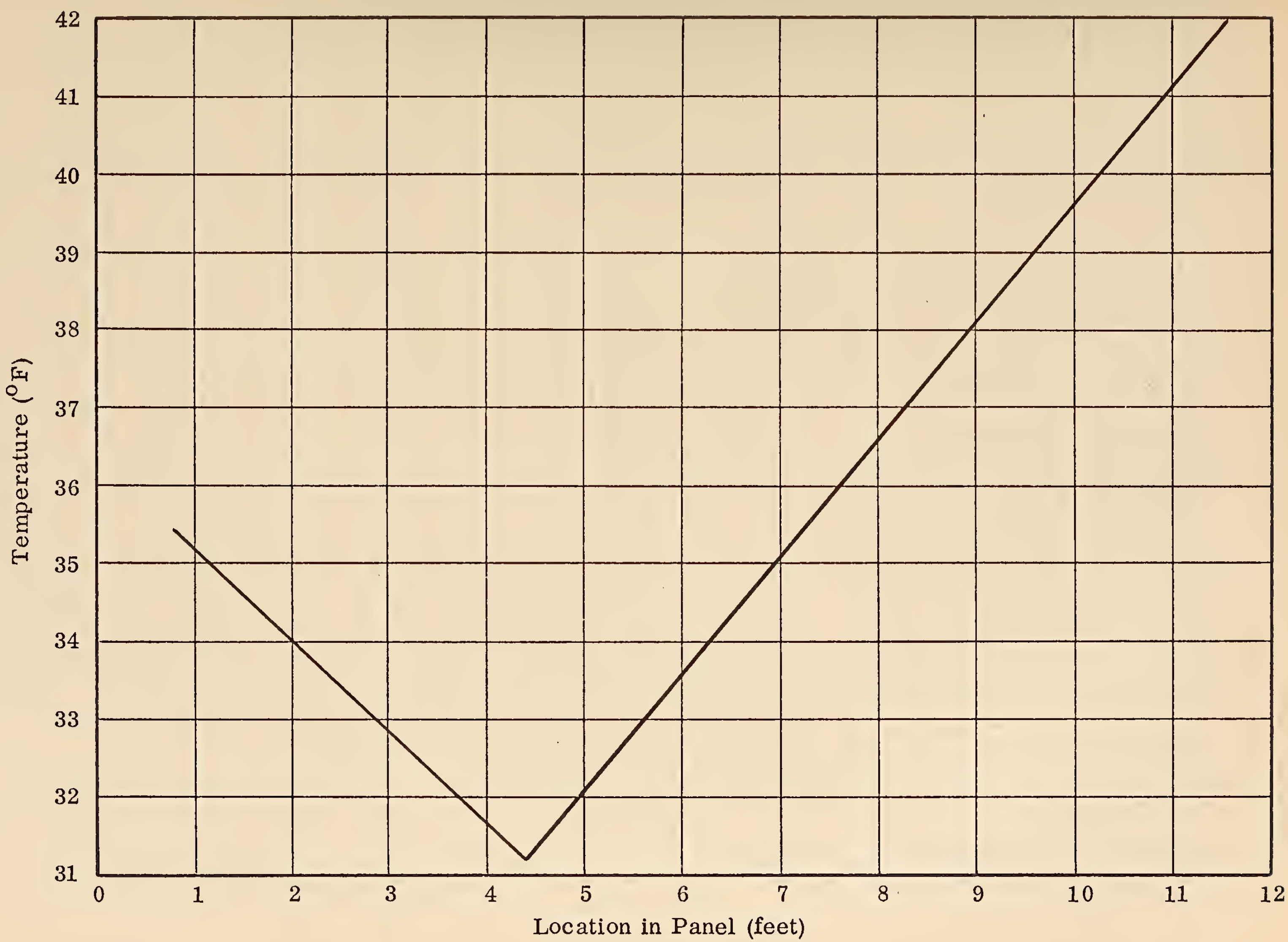


FIGURE V-1

TEMPERATURE VARIATIONS IN RIGHT PIPES, PANEL F, TEST # 2005
(Time 06:00)

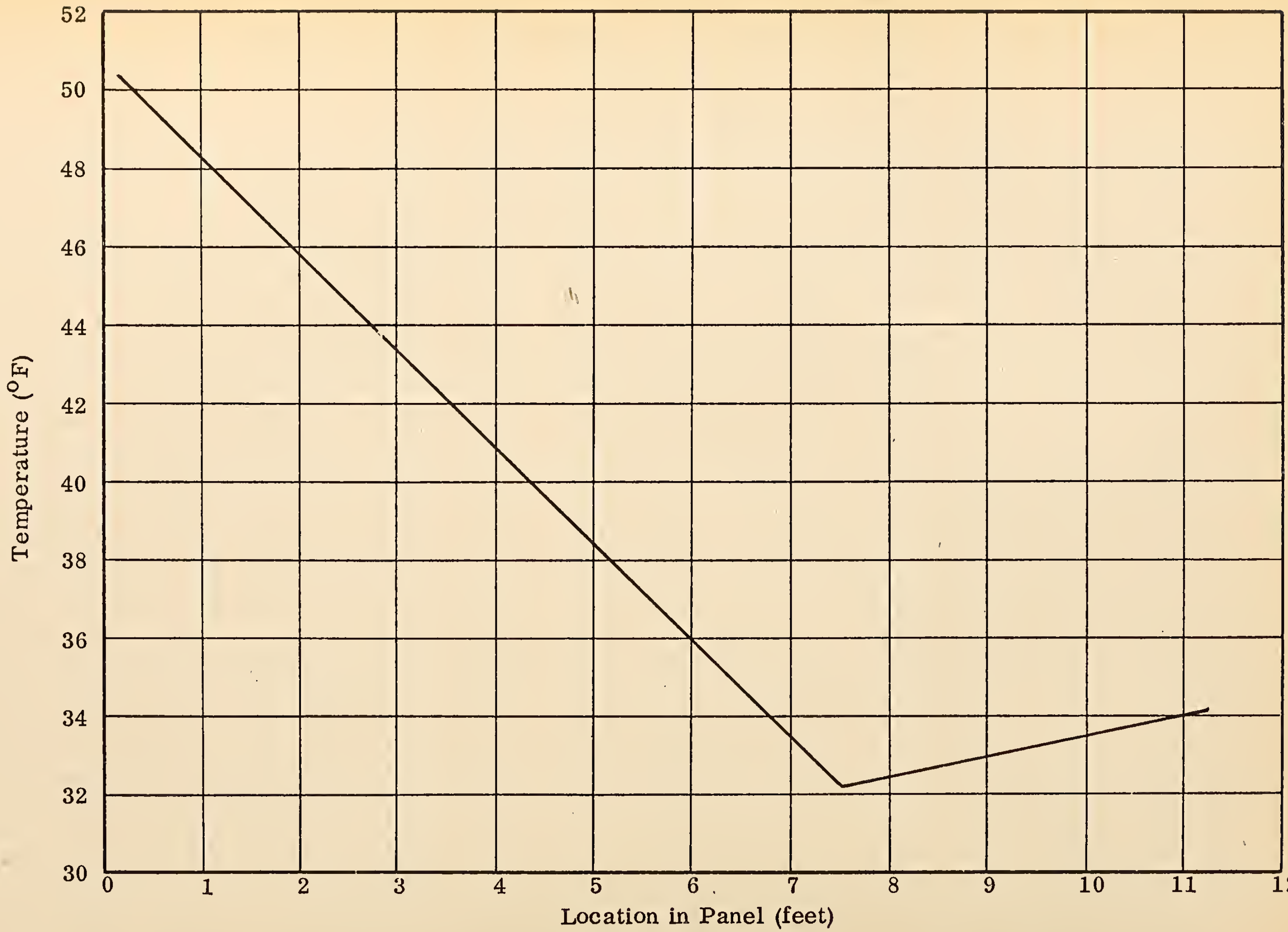


FIGURE V-2

TEMPERATURE VARIATIONS IN LEFT PIPES, PANEL F, TEST # 2005
(Time 06:00)

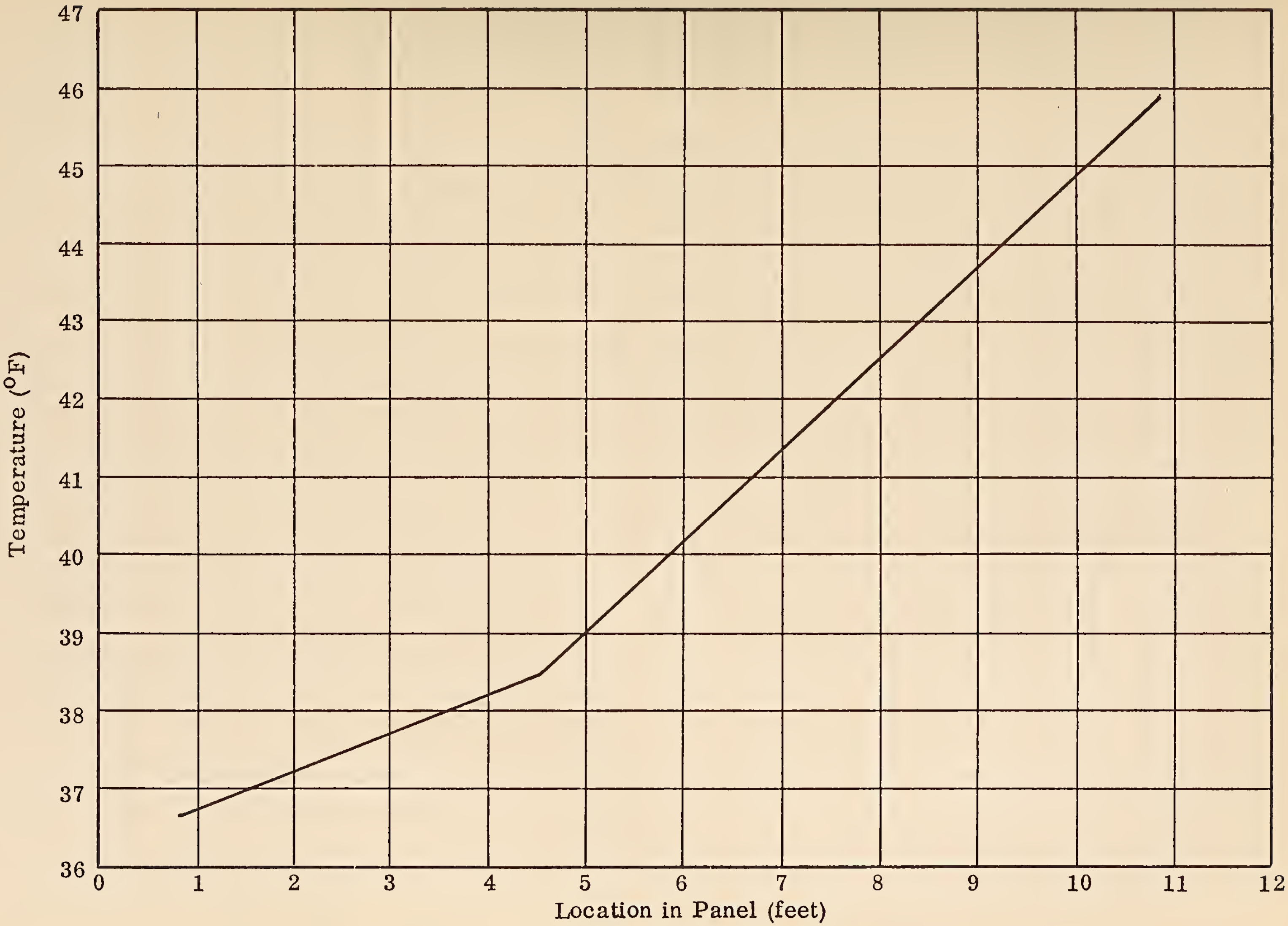


FIGURE V-3

TEMPERATURE VARIATIONS IN RIGHT PIPES, PANEL F, TEST # 1007
(Time 04:00)

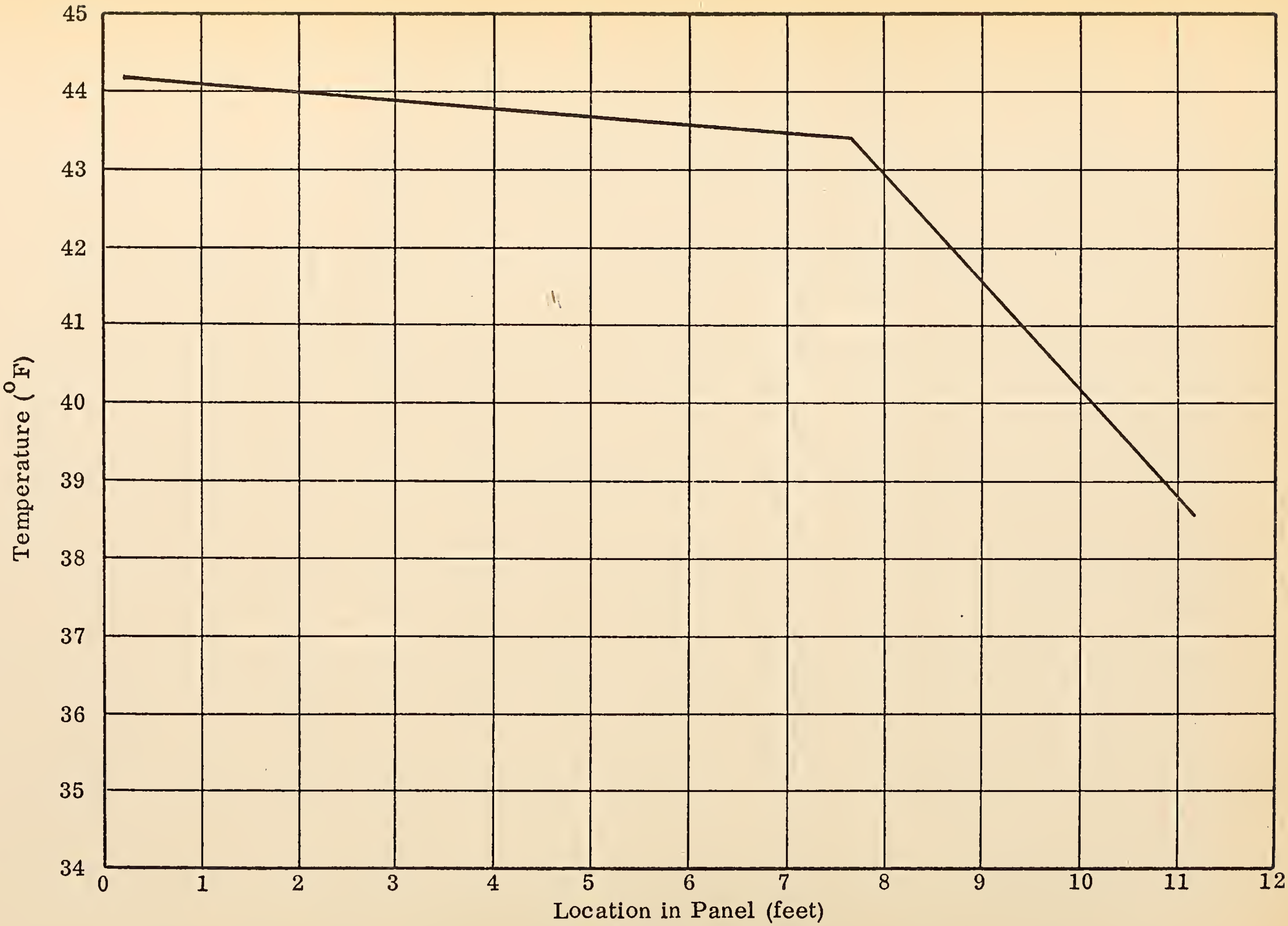


FIGURE V-4

TEMPERATURE VARIATIONS IN LEFT PIPES, PANEL F, TEST # 1007
(Time 04:00)

The application of the mathematical model to analysis of the control slab allows the determination of the thermal losses, ground heat inputs, pavement conductivity, and pavement specific heat in the absence of a heat pipe source. In the model, these values are assumed to be 1.0 Btu/hr-ft-^{o}F and 0.156 Btu/lb-^{o}F, respectively. Temperature probes within the control slab yield the actual temperature distribution within the slab as a function of time. Using the actual initial temperature profile to determine the required initial temperatures for each node, the temperature probe predictions for various times can be compared to actual recorded data for various assumed values of the surfaces losses and ground heat inputs. This procedure was repeatedly applied to Test 2008 until a satisfactory match was achieved. The actual and predicted profiles are shown in Figure V-5 for a nodal ground conductance of 0.01 Btu/hr-^{o}F and the surface conductance defined by the loss equations from Section II for a dry surface:

$$Q_{loss} = Q_{cv} + Q_r = \frac{(1 + 0.3\ v)\ (T_s - T_a)}{3.41} + (0.22\ (T_s - T_a) + 3.50)\ (1 - 0.75\ n)$$

and

$$\text{Surface Conductance} = \frac{Q_{loss}}{T_s - T_a} = \frac{1 + 0.3\ v}{3.41} + \left(0.22 + \frac{3.50}{T_s - T_a}\right)(1 - 0.75\ n)$$

The comparison of predicted to actual profiles can be based on several criteria. Firstly, for the range of temperatures at the bottom of the slab, the predicted slopes at the bottom surface match the experimental results. This suggests that the assumption on ground conductance is correct. Secondly, although the predicted temperature profiles are displaced slightly from the actual temperatures, this displacement remains constant, indicating the assumption of specific heat is correct. Also, the predicted slope at all

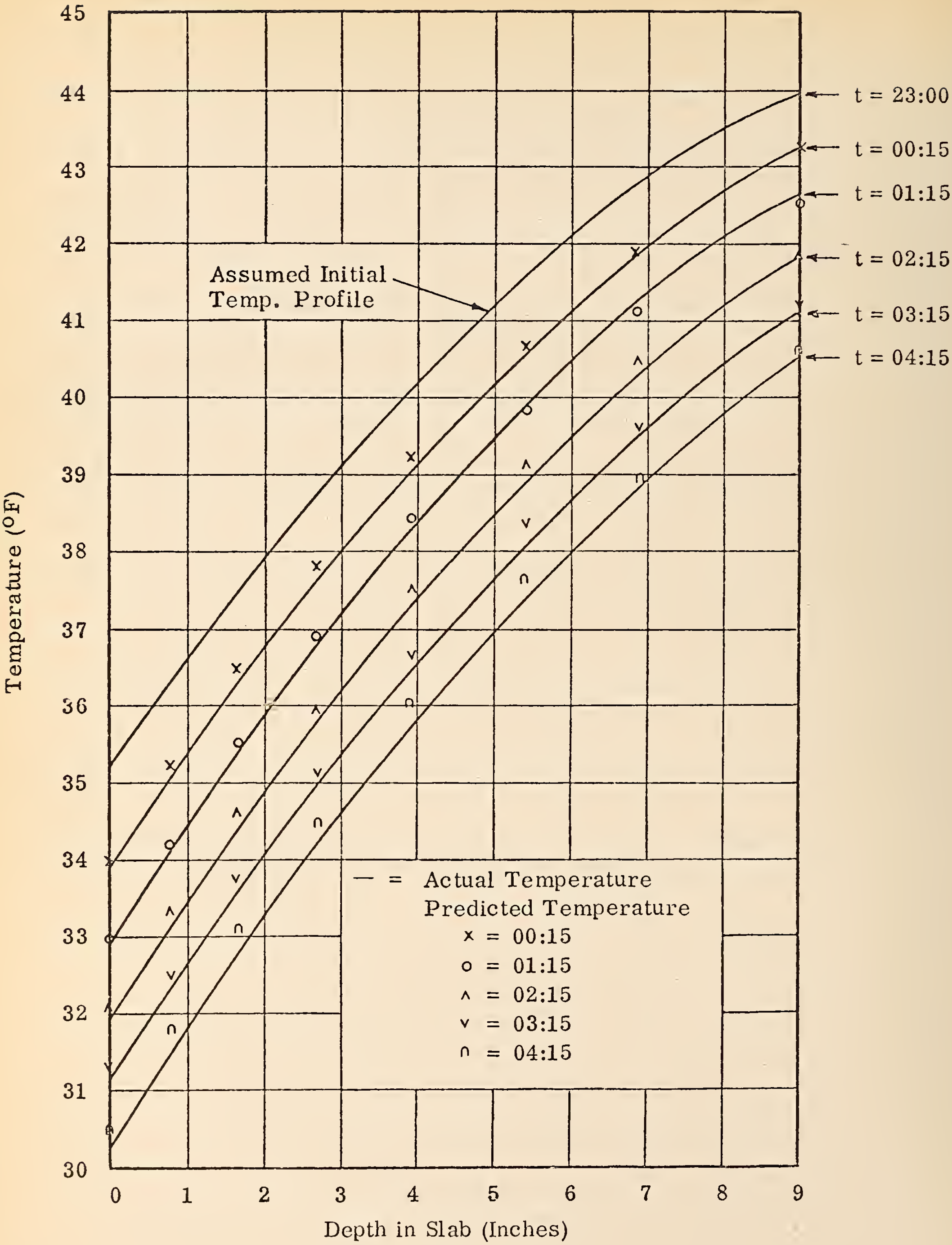


FIGURE V-5

ACTUAL VS. PREDICTED CONTROL SLAB TEMPERATURE PROFILES
(TEST #2008)

depths matches the actual slope very well. This implies that the assumed conductivity is correct. Lastly, the slope at the surface matches (for the corresponding match of surface temperature) indicating the equation for the surface losses is correct.

Having established these system parameters by control slab analysis, the model can be applied to the electrical heat pipe slab to determine the interface resistance between the heat pipe and the concrete. In this application, the model predicted the thermal behavior of an actively heated slab (Panel C during Test 2008) where the heat input of the pipe is known. Since the interface resistance only affects the operating temperature of the heat pipe, this application should provide a check on those assumptions made for the control slab for the case of a much larger surface-ambient temperature difference. A comparison of actual and predicted temperature profiles is shown in Figure V-6. The assumptions in this case were the same except for the ground-concrete conductance and the ground source temperature. These adjustments were made to model the actual ground input. The reason for this variation can be explained by the fact that the power had been on for a period of 34 days prior to the test. This probably resulted in the preheating of the earth directly below the slab and, consequently, a higher sensible heat input from the ground. The ground conductance is based on the earth source reference temperature at a depth of 40 feet below the slab, while the actual heat input from the earth is only affected by a small portion of the ground mass directly under the slab. The good correlation between actual and predicted temperature profiles provides additional verification of the mathematical model.

The analysis of the electrical heat pipe slab also results in the determination of the concrete-pipe resistance. A comparison of the predicted and actual heat pipe temperature versus time (for Panel C during Test 2008) is shown in Figure V-7 for perfect

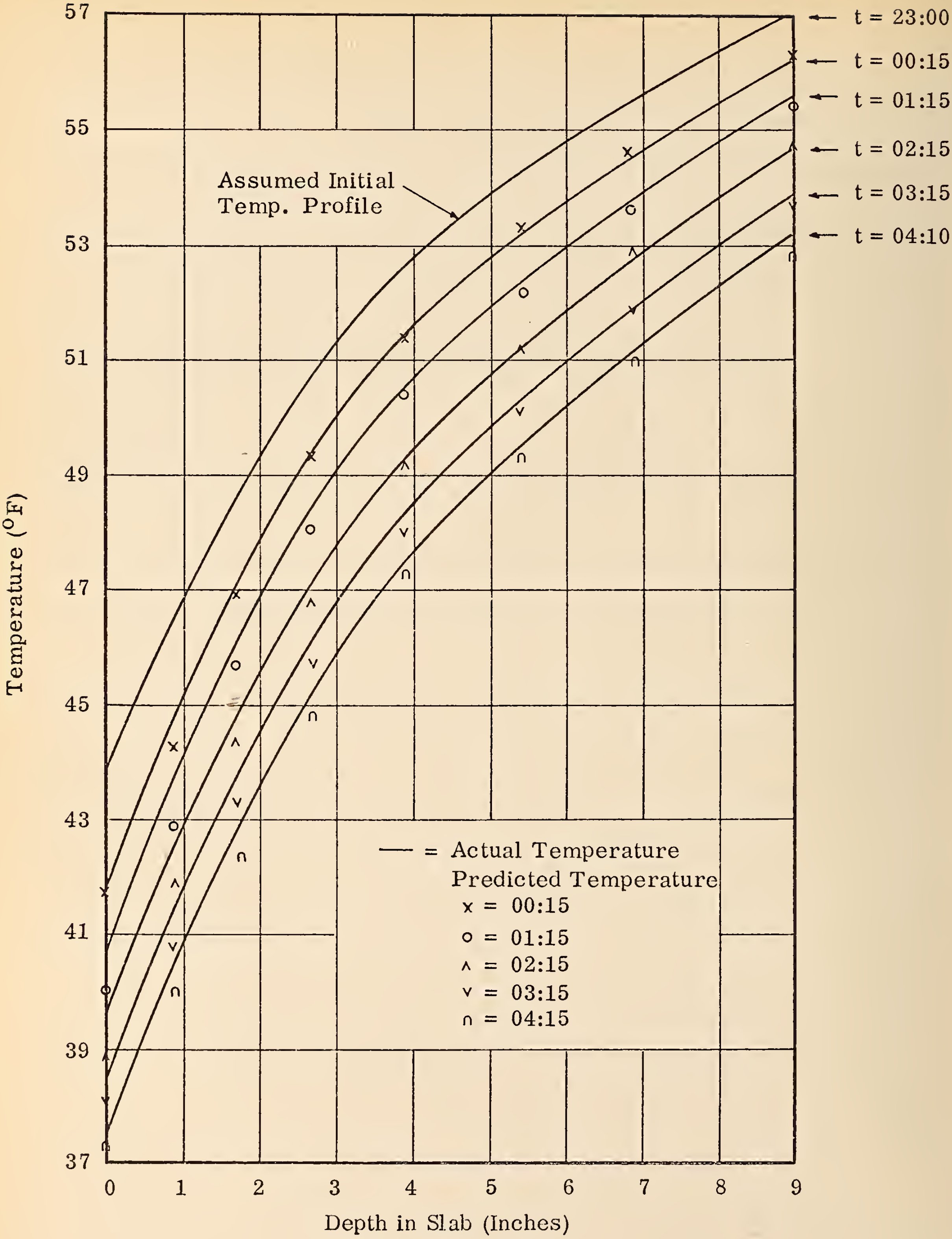


FIGURE V-6

ACTUAL VS. PREDICTED PANEL C TEMPERATURE PROFILES
(TEST #2008)

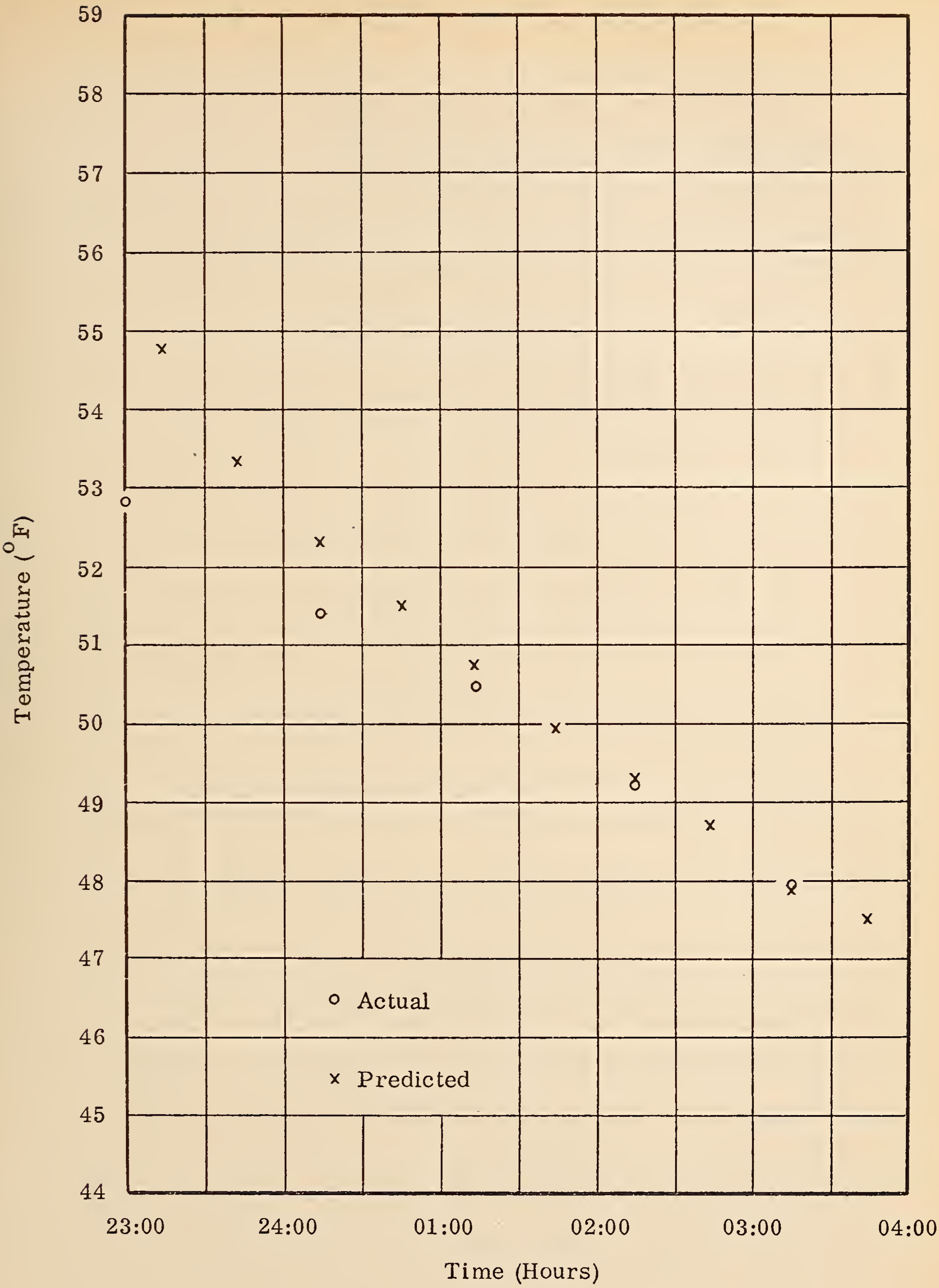


FIGURE V-7

ACTUAL VS. PREDICTED PANEL C HEAT PIPE TEMPERATURES
(TEST 2008)

thermal contact. The excellent agreement indicates that the interface resistance is negligible when compared to the resistance between the heat pipe and ambient.

C. Melting on Electrically Heated Heat Pipe Slabs

The mathematical model must also be validated for snow or ice melting conditions. To accomplish this, the behavior of Panel A, an electrically heated slab of 4" spacing, was predicted for conditions corresponding to Ice Melt Test 2004. In this case, the assumptions for system parameters were the same; however, some adjustment to the ground conductance was necessary to account for preheating, and the surface conductance was made large to provide an isothermal concrete surface associated with the melting of ice. The comparison of predicted and actual temperature profiles is shown in Figure V-8, and the predicted and actual heat pipe temperature versus time is shown in Figure V-9. It appears that all the previous assumptions are still supported and that the model is equally applicable for dry or ice melt conditions.

Once the electrical slab has been modeled such that a predicted versus actual temperature profile and heat pipe temperature correlation has been obtained, the surface flux resulting from the model may be used to calculate ambient losses. In order to do this, the experimental melt rate must be known. This melt rate is normally determined by weighing the melt water removed from the slabs. However, this method of melt rate determination cannot account for water losses due to evaporation and concrete saturation. For this reason, an adjusted melt rate can be determined by subtracting from the weight of ice applied during the test, 75 percent of the weight of slush removed, assuming that 25 percent of the total weight removed is melted water.

The resulting ambient losses calculated using both melt rates are shown in Table V-3 for Ice Melt Tests 2004 and 2005. The electrical panel used in Test 2004

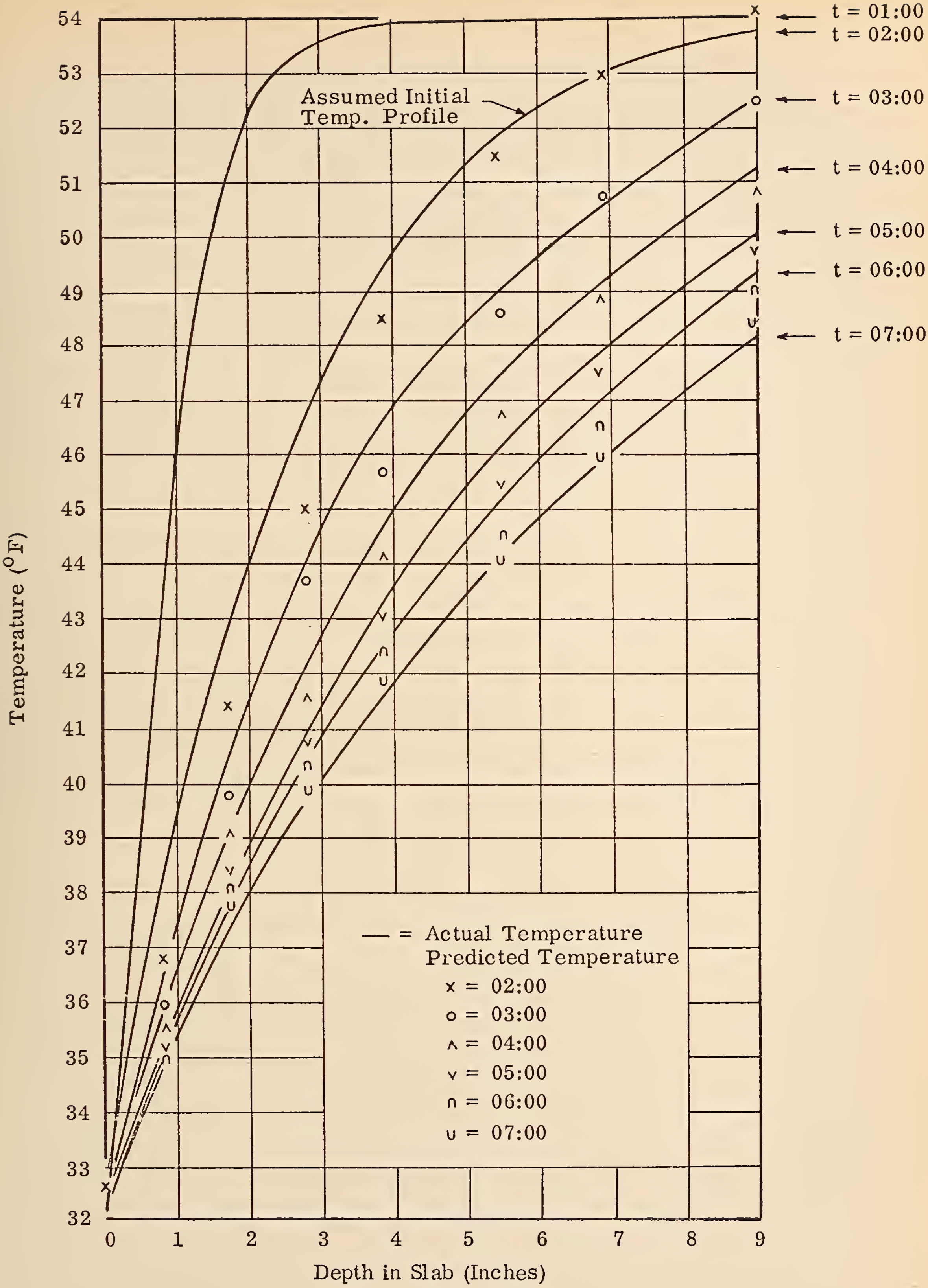


FIGURE V-8

ACTUAL VS. PREDICTED PANEL A TEMPERATURE PROFILES
(TEST 2004)

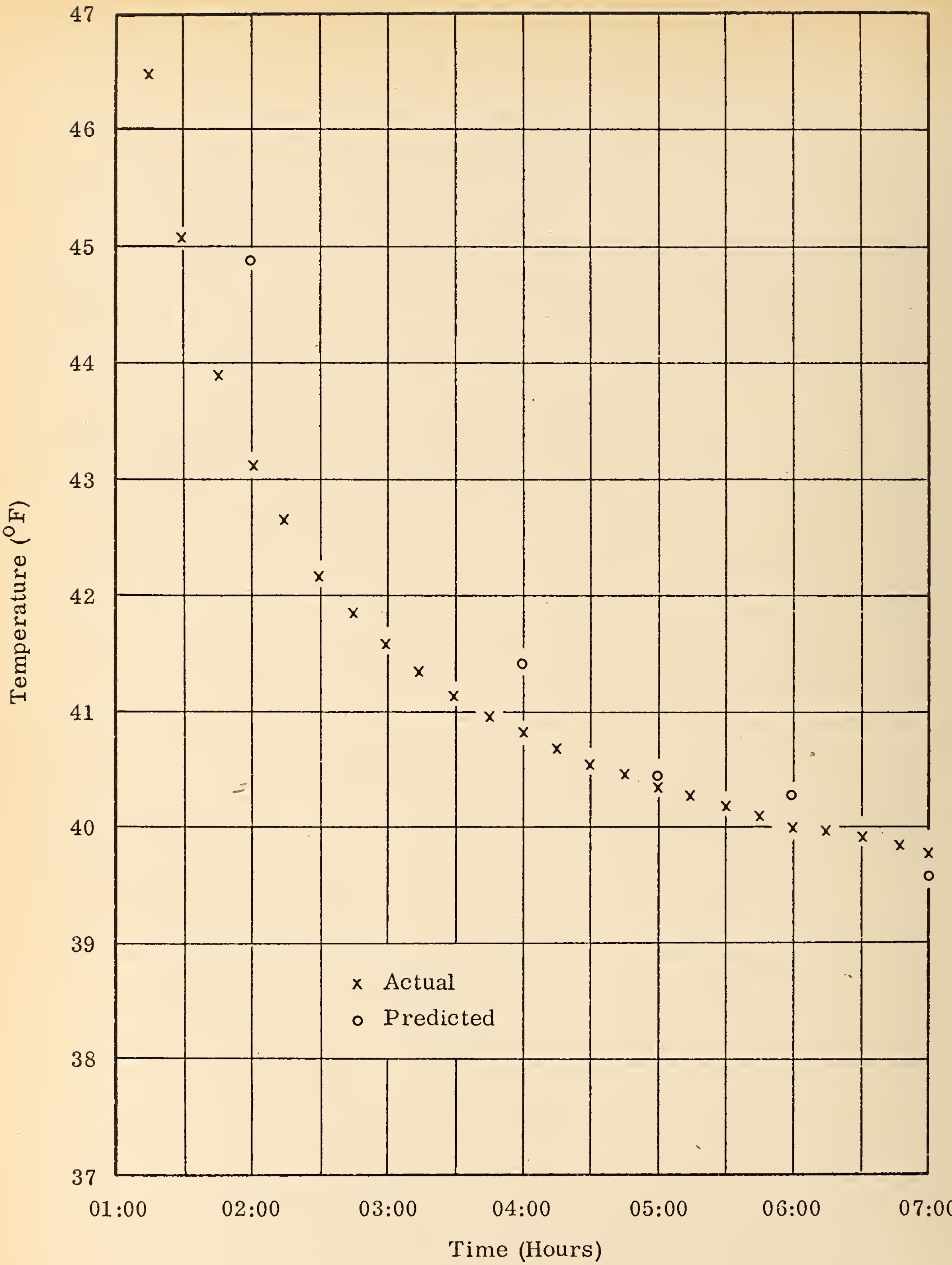


FIGURE V-9

ACTUAL VS. PREDICTED PANEL A HEAT PIPE TEMPERATURES
(TEST 2004)

	Test 2004 Panel A	Test 2005 Panel B
Ambient Temperature (^{o}F)	31.5	23.5
Wind Speed (mph)	5	0
Relative Humidity (%)	50	53
Cloud Cover (tenths)	10	3
Heat of Fusion (watts/ft^2) for Recorded Melt Rate	18.1	8.2
Heat of Fusion (watts/ft^2) for Adjusted Melt Rate	20.8	8.1
Heat Pipe Flux (watts/ft^2)	9.8	10
Predicted Surface Flux (watts/ft^2)	19.6	14.3
Ambient Losses for Recorded Melt Rate (watts/ft^2)	1.5	6.1
Ambient Losses for Adjusted Melt Rate (watts/ft^2)	-1.2	6.2

TABLE V-3

AMBIENT LOSSES FOR ICE MELT TESTS #2004 AND #2005

was Panel A, and Panel B was used in Test 2005. Also shown in the table are the predicted surface fluxes, the heat of fusion associated with both methods of melt rate determination, and the pertinent ambient conditions existing during both tests. It is important to note that the higher predicted surface flux for Panel A during Test 2004 for essentially the same heat pipe flux, is due to the greater sensible heat loss of this panel (resulting from its transient adjustment to the higher ambient temperature prior to the application of ice). The ambient losses calculated from the adjusted melt rate during Test 2004 are negative, which is a physically impossible situation. Evidently, this result is due to an erroneous assumption inherent in the analytical technique. However, because the ambient temperature is nearly the same as the melting point of ice and the extent of cloud cover is high, the ambient losses should be very small.

The ambient losses determined by electrical panel analysis can be assumed to apply to all other panels tested simultaneously if the panels are melting ice and if the surface coverings are the same. During Test 2004, the ambient losses are taken to zero; and, for Test 2005, ambient losses are assumed to be 6.2 watts/ft^2. These losses will be used later in the evaluation of the thermal behavior of the earth heat pipe slabs.

D. Thermal Performance and Melting on Earth Heat Pipe Slabs

Through application of the mathematical model to the control slab and the electrical slab, it was possible to match predicted and actual temperature profiles and heat pipe temperatures as a function of time, for specific assumptions for the thermal losses, the ground heat inputs, pavement conductivity, pavement specific heat, and the concrete-heat pipe interface resistance. The use of this model, with the previous assumptions, in the analysis of the earth heat pipe slabs allows the determination of the ground to

heat pipe resistance. However, application of the model to an earth heat pipe slab is made more difficult because of condenser blockage evidenced on both Panels E and F. The extent of condenser blockage showed a marked increase over the time period between the first winter's and the second winter's testing, indicating the condenser blockage is largely due to generation of noncondensible gas. This does not mean, however, that some of the blockage is not due to liquid traps created during the installation of the system.

Because of this blockage, the depth probes in Panels E and F do not reflect the heat input from two active heat pipes located on either side of the probe. Thus, comparison of predicted and actual temperature distributions is no longer possible; and comparison of predicted and actual heat pipe temperature as a function of time can be made only with some reservations. The initial heat pipe temperature which is required in the model is taken from the average initial temperature existing at the top of the vertical portion of each heat pipe. The initial temperature profile is taken from the experimental values of the depth probe. This choice of initial conditions results in an imbalance between heat pipe and nodal temperatures which, in turn, creates oscillations of the predicted heat pipe temperature as a function of time. However, the oscillations are dampened and adequate correlation with actual temperatures can be made.

Due to the absence of the actual initial conditions, those methods previously employed for the determination of system parameters cannot be used to determine the heat pipe to ground resistance. However, all of the ice melt tests which have been analyzed on the earth panels have been conducted for a time period sufficiently long to enable the actual heat pipe temperature to approach a steady-state value.

Thus, the only basis by which we can determine the heat pipe to ground resistance is to match the actual steady-state value of heat pipe temperature reached during an ice melt test. This method of analysis can also be applied to a dry surface if the ambient conditions are relatively stable for an extended period of time.

Determination of the heat pipe to ground resistance associated with the length of the heat pipe node in the model is relatively straightforward using this method of analysis. However, the conversion of this nodal resistance to the equivalent resistance for the entire pipe can only be done once the active condenser length is known. Normally, the inactivity of a portion of the heat pipe's condenser is indicated by a severe temperature gradient between two points within the condenser. However, an accurate representation of the extent of blockage determined in this manner is dependent upon the frequency of thermocouple instrumentation. Many of the heat pipes in Panels E and F have only three thermocouples located on the 12-foot condenser section, so the accuracy of determining the extent of blockage in this manner is severely limited.

For this reason, another method for determining the extent of condenser blockage was instrumented. It was previously established that the ambient losses for an electrical heat pipe slab can be determined by subtracting the heat of fusion from the model-predicted surface flux. If it is assumed that the surface covering above the active condenser sections on the earth heat pipe panels is the same as the surface covering above the heat pipes in the electrical panel, then the ambient losses must be the same for active regions of both panels. Adding these losses to the experimental melt rate observed on the earth panel, a convenient summation of the actual flux at the concrete surface results. Dividing the actual surface flux by the predicted

surface flux associated with the nodal heat pipe to ground resistance that yielded a heat pipe temperature match results in the fractional active condenser length of an average heat pipe. This active condenser length will then allow the conversion of nodal heat pipe to ground resistance to the total heat pipe to ground resistance.

This method of analysis was applied to melt tests for Panels E and F for both Winters of 1972-1973 and 1973-1974. The comparison of actual and predicted steady-state heat pipe temperatures for Panel E during Test 2004 and Test 1007 and Panel F during Test 2005 and Test 1007 are shown in Figures V-10, V-11, V-12, and V-13, respectively. The ambient losses during Test 2004 were determined from Panel A; while for Test 2005, Panel B was used. During Test 1007, no electrical panel was tested concurrently so the losses were calculated by comparison of ambient conditions during this test to those which existed during Tests 2004 and 2005. For each test, the ambient losses, the heat of fusion, fractional active condenser length, and demonstrated ground--heat pipe resistance are shown in Table V-4.

This notable decrease in the active condenser length on both panels indicates the generation of noncondensible gas. Panel F shows the greatest decrease in active condenser length, which can be attributed to the greater heat pipe length, and hence greater area for gas generation. A matter of concern is the indicated lower resistance during the later year. A slight decrease should be expected since many cavities found in the earth fill around the pipes had been filled, although this cannot entirely account for the differences. Another source for the discrepancy could be the assumption made for the losses during Test 1007. But, rather than basing the analysis on this latest year's testing, it is suggested that the values of the ground to heat pipe resistance for heat pipes with 30-foot and 40-foot vertical lengths be taken as 0.129 ^{o}F/watt and 0.081^{o}F/watt, respectively.

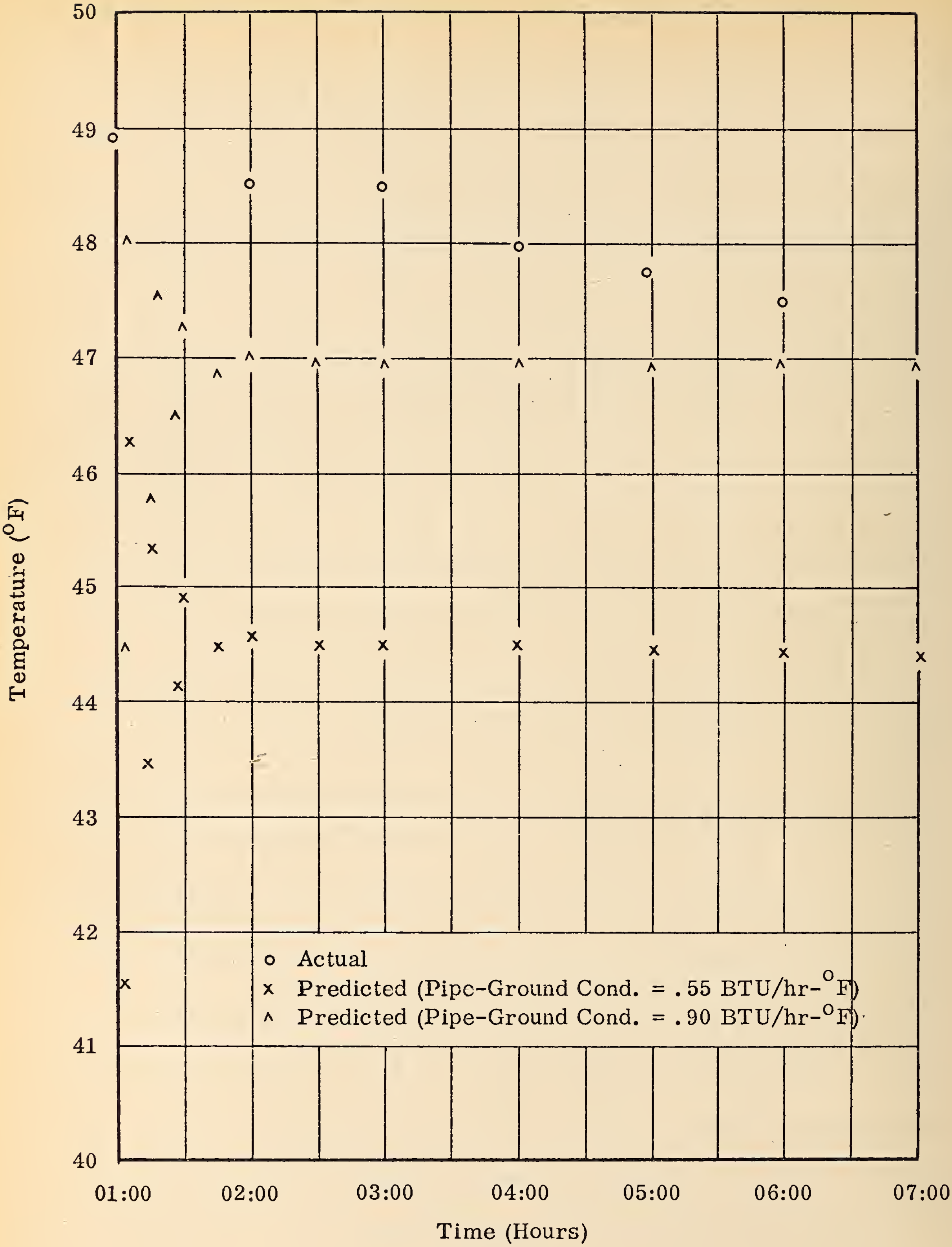


FIGURE V-10

ACTUAL VS. PREDICTED PANEL E HEAT PIPE TEMPERATURES (TEST 2004)

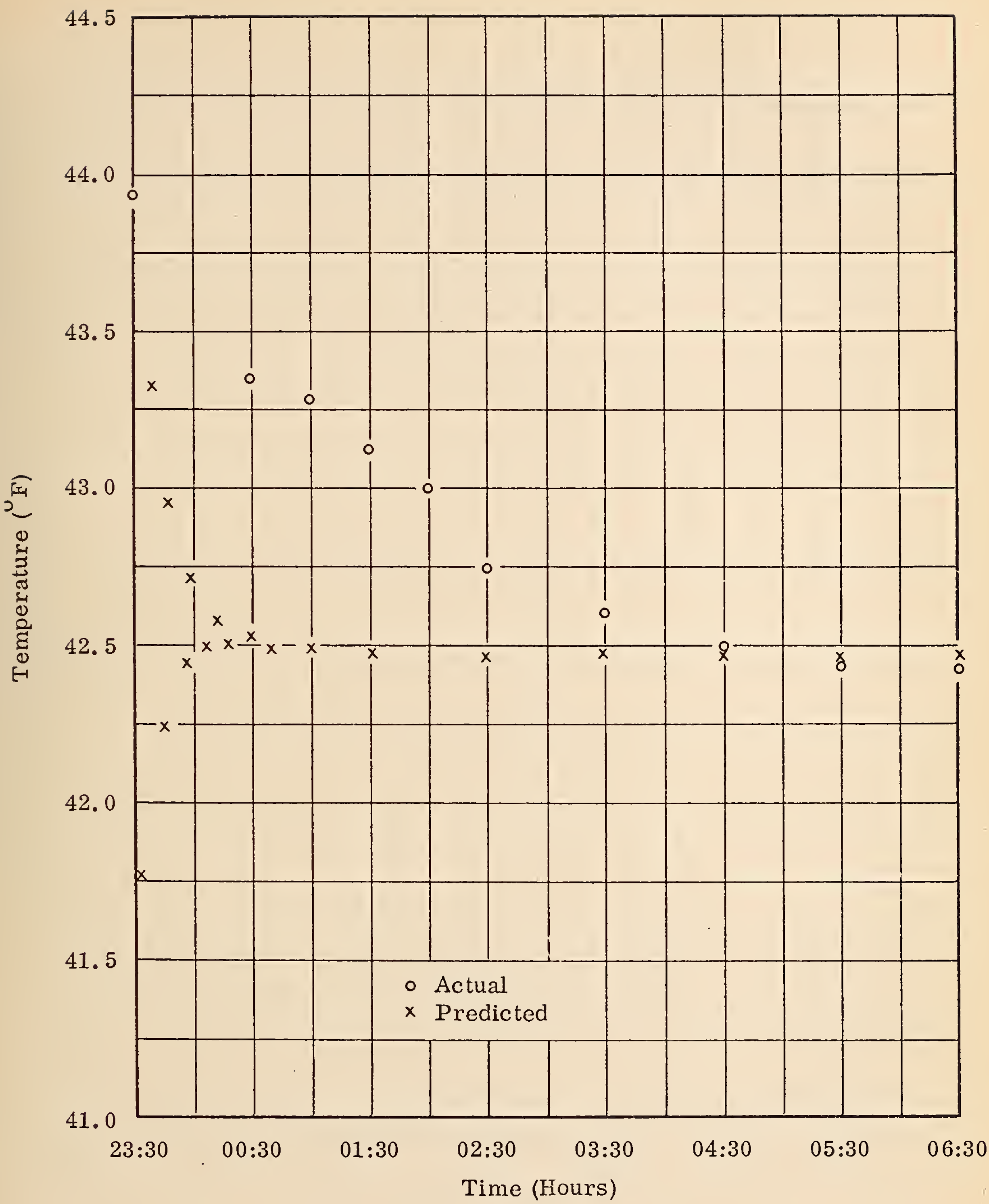


FIGURE V-11

ACTUAL VS. PREDICTED PANEL E HEAT PIPE TEMPERATURES (TEST 1007)

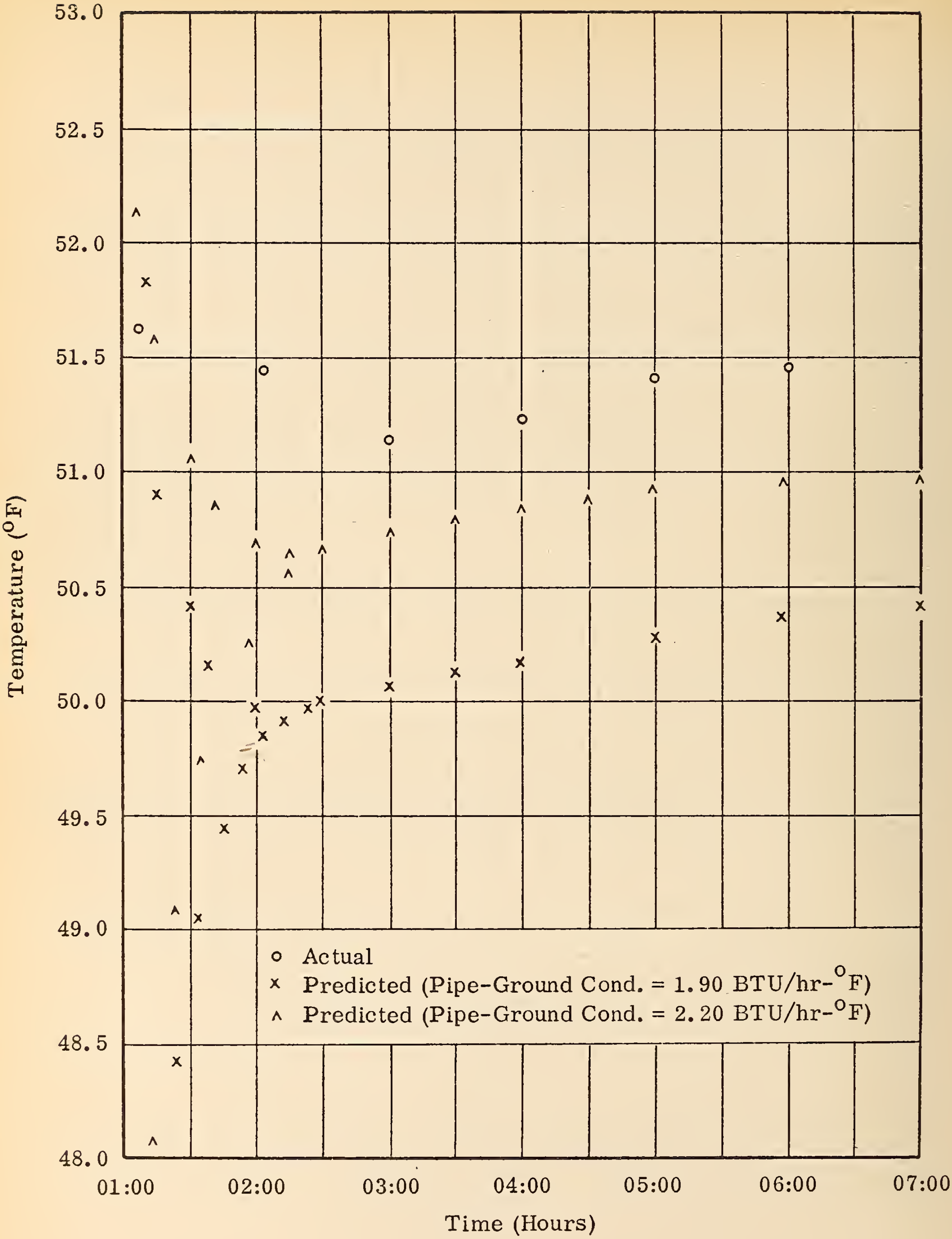


FIGURE V-12

ACTUAL VS. PREDICTED PANEL F HEAT PIPE TEMPERATURES
(TEST 2005)

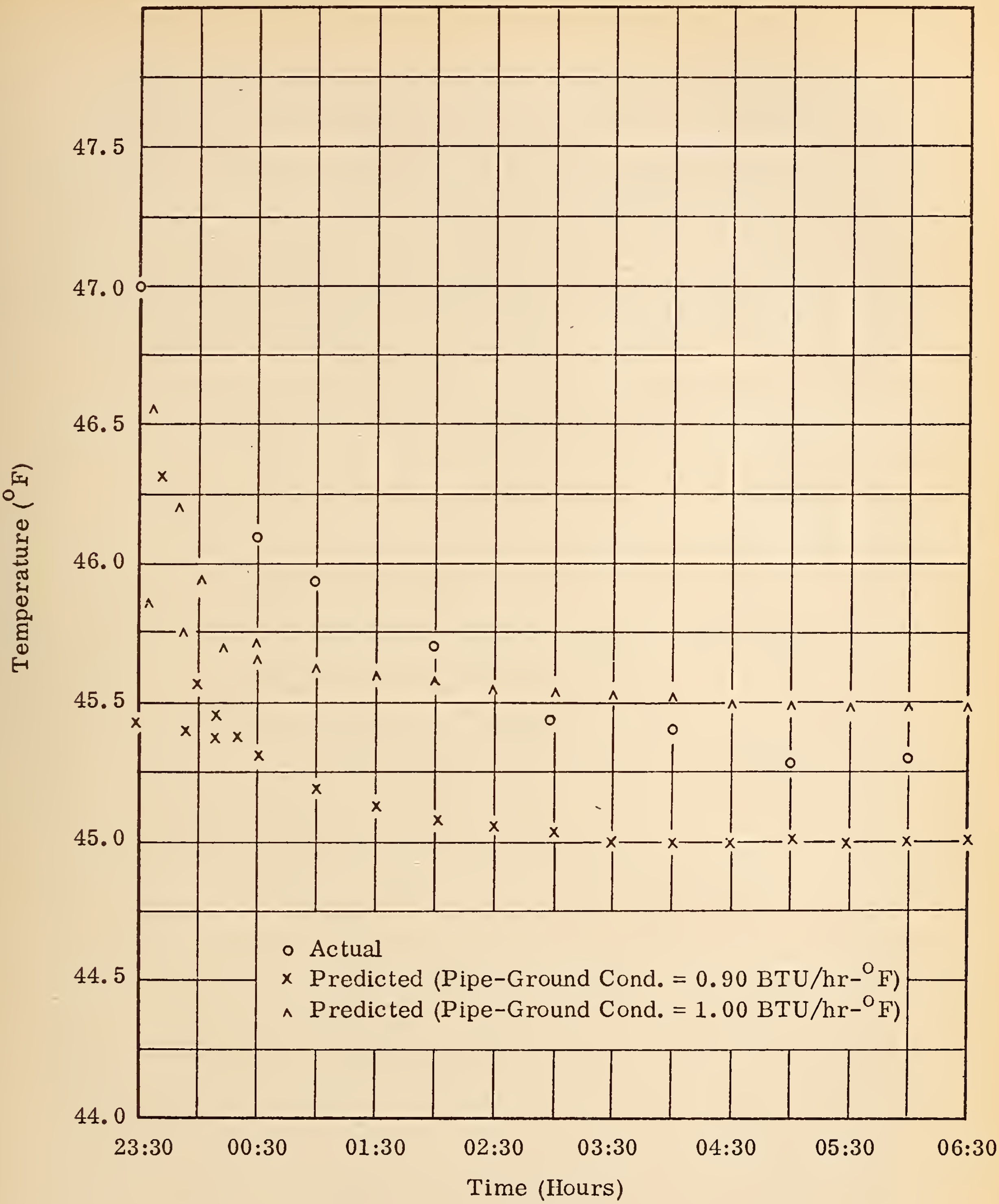


FIGURE V-13

ACTUAL VS. PREDICTED PANEL F HEAT PIPE TEMPERATURES (TEST 1007)

Panel	Test	Q_{loss} (Watts/Ft^2)	Q_f (Watts/Ft^2)	$\frac{L_c \text{ (Active)}}{L_c \text{ (Total)}}$	R_{p-g} (^oF/Watt)	Ground Source Temperature
E	1007	4.2	7.79	0.80	0.165	52.9
E	2004	0	14.4	0.67	0.108	56.0
E	2005	6.23	7.55	0.67	0.113	56.0
F	1007	4.2	11.69	0.81	0.092	52.9
F	2005	6.23	4.96	0.43	0.070	56.0

Note: All resistances are based on the average ground temperature taken from the surface to a depth of 40 feet.

TABLE V-4

SUMMARY OF DATA INCLUDING CALCULATED GROUND-PIPE RESISTANCES

VI. HIGHWAY ENGINEER'S USER DATA

A. General Requirements

The winter climate in a particular location specifies the earth heat pipe pavement heating system. The single, most important parameter specified by the climate is the surface heat flux (watts/ft^2). The surface heat flux is determined by the system net thermal losses and by the specified snow melting capacity (inches/day). In Section II, the thermal losses are defined in terms of the ambient conditions and, in summary, are:

$$\dot{q}_{cv} = (1 + 0.3\ v)\ (T_s - T_a)\ /\ 3.41 \qquad \text{VI-1}$$

$$\dot{q}_r = (0.22\ (T_s - T_a) + 3.5)\ (1 - 0.75\ n) \qquad \text{VI-2}$$

$$\dot{q}_e = (0.0201\ v + 0.055)\ (p_{v,w} - p_{v,a})\ (h_{f,g})\ /\ 3.41 \qquad \text{VI-3}$$

where:

$\dot{q}_{cv}$ = convection heat loss (watts/ft^2)

$\dot{q}_r$ = radiation heat loss (watts/ft^2)

$\dot{q}_e$ = evaporation heat loss (watts/ft^2)

v = wind speed (mph)

T_s = temperature of pavement surface (^oF)

T_a = temperature of air (^oF)

n = cloud cover (tenths)

$p_{v,w}$ = saturation vapor pressure at the pavement surface temperature (inches of Hg)

$p_{v,a}$ = atmospheric vapor pressure (inches of Hg)

$h_{f,g}$ = enthalpy of saturated vapor at the at the pavement surface temperature (Btu/lb)

During a snowfall, the cloud cover is assumed to be complete and n equals one. The atmospheric vapor pressure is determined by the relative humidity, and its determination is presented below.

The heat flux associated with melting snow is given by:

$$\dot{q}_f = 0.908\ \dot{r} \qquad \text{VI-4}$$

where: $\dot{q}_f$ = fusion heat loss (watts/ft^2)

$\dot{r}$ = rate of snowfall (inches/day)

It is assumed that 10 inches of snow is equivalent to one inch of water. The day is defined as 24 hours throughout this section.

Therefore, the required surface heat flux is given by the balance:

$$\dot{q}_s = \dot{q}_{cv} + \dot{q}_r + \dot{q}_e + \dot{q}_f \qquad \text{VI-5}$$

where: q_s = surface heat flux (watts/ft^2)

To facilitate the calculation of the thermal losses, Figures VI-1, VI-2, VI-3, and VI-4 are provided and these correspond to Equations VI-1, VI-2, VI-3, and VI-4, respectively.

<u>Example VI-1</u>

Assume that the following conditions exist during a snowfall and find the surface heat flux $\dot{q}_s$:

T_s = 32°F (pavement surface temperature at a condition where snow and water are present)

T_a = 25°F (air temperature)

v = 5 mph (average wind speed)

R.H. = 65% (air relative humidity)

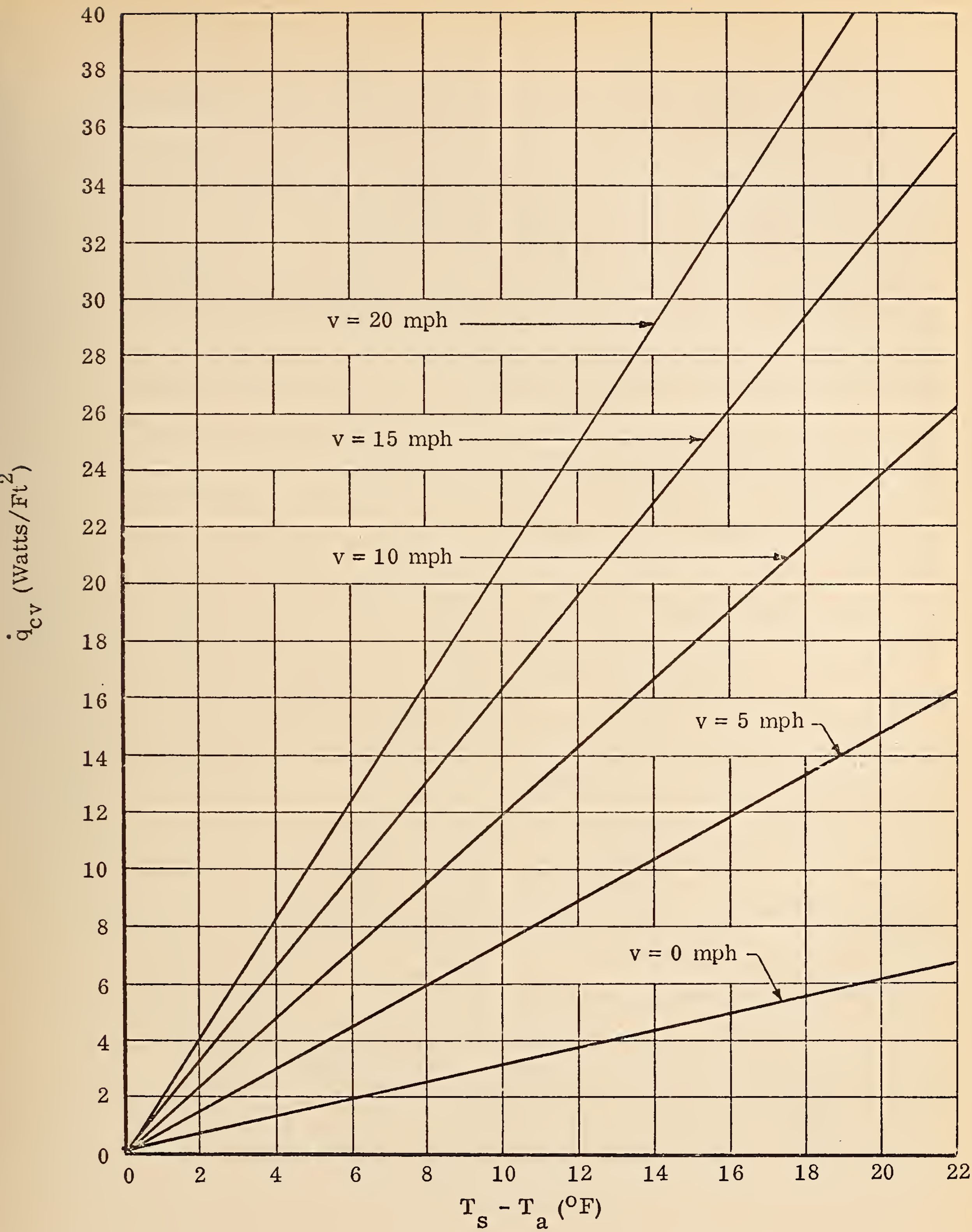


FIGURE VI-1

CONVECTION LOSSES AS A FUNCTION OF AMBIENT AND SURFACE TEMPERATURE FOR VARIOUS WIND SPEEDS

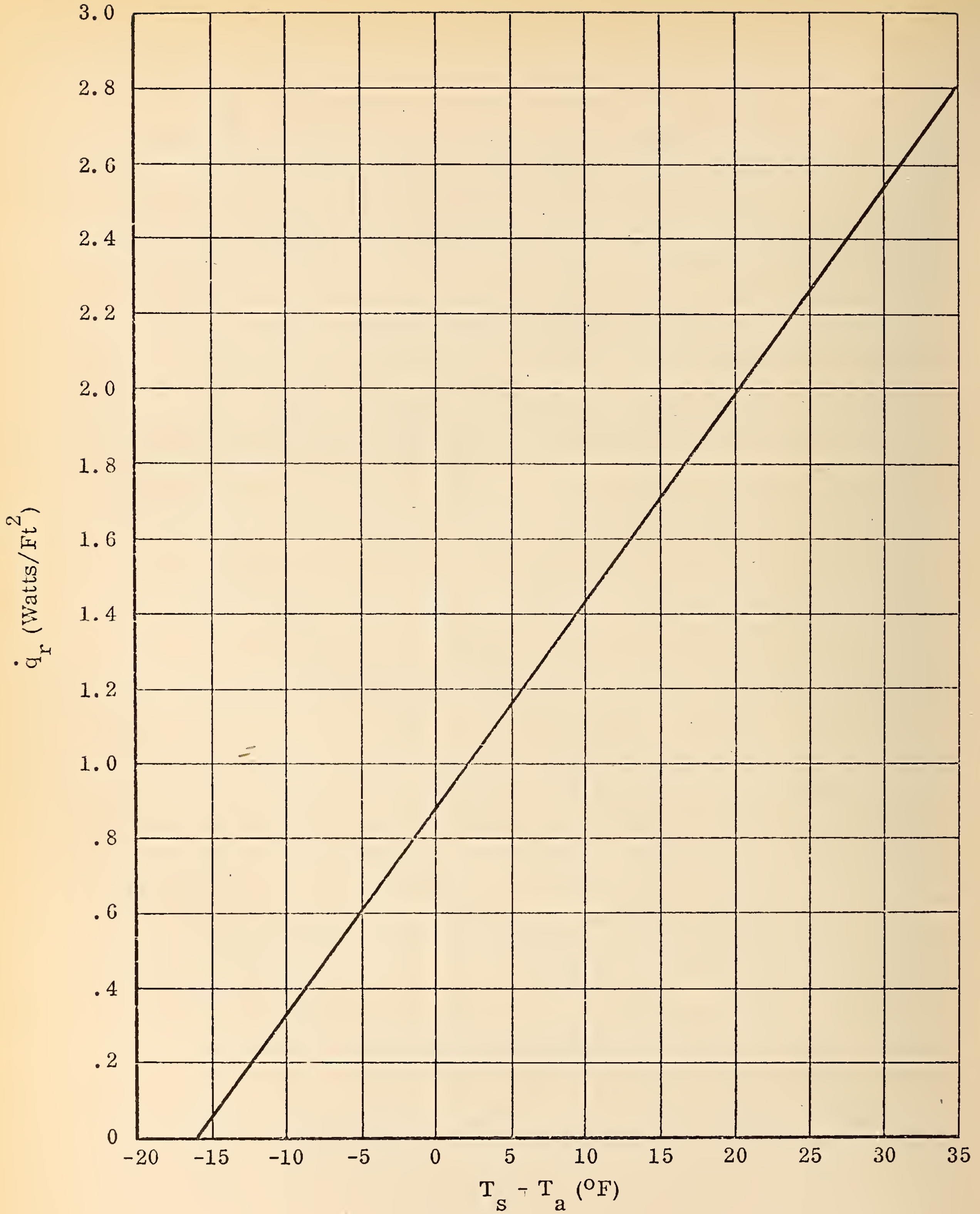


FIGURE VI-2

RADIATION LOSSES AS A FUNCTION OF AMBIENT AND SURFACE TEMPERATURE

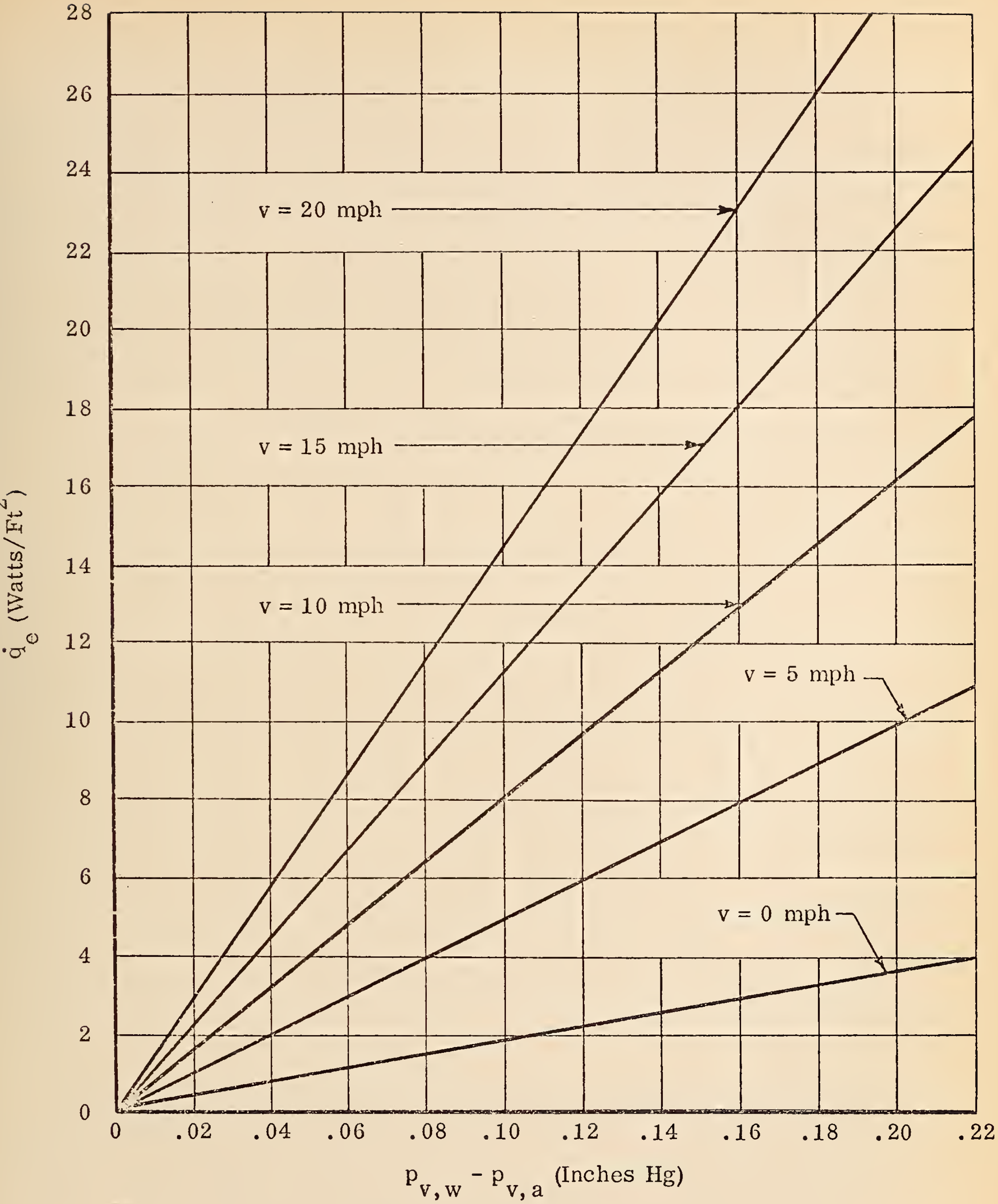


FIGURE VI-3

EVAPORATION LOSSES AS A FUNCTION OF VAPOR PRESSURE DIFFERENCE BETWEEN SURFACE AND AMBIENT FOR VARIOUS WIND SPEEDS

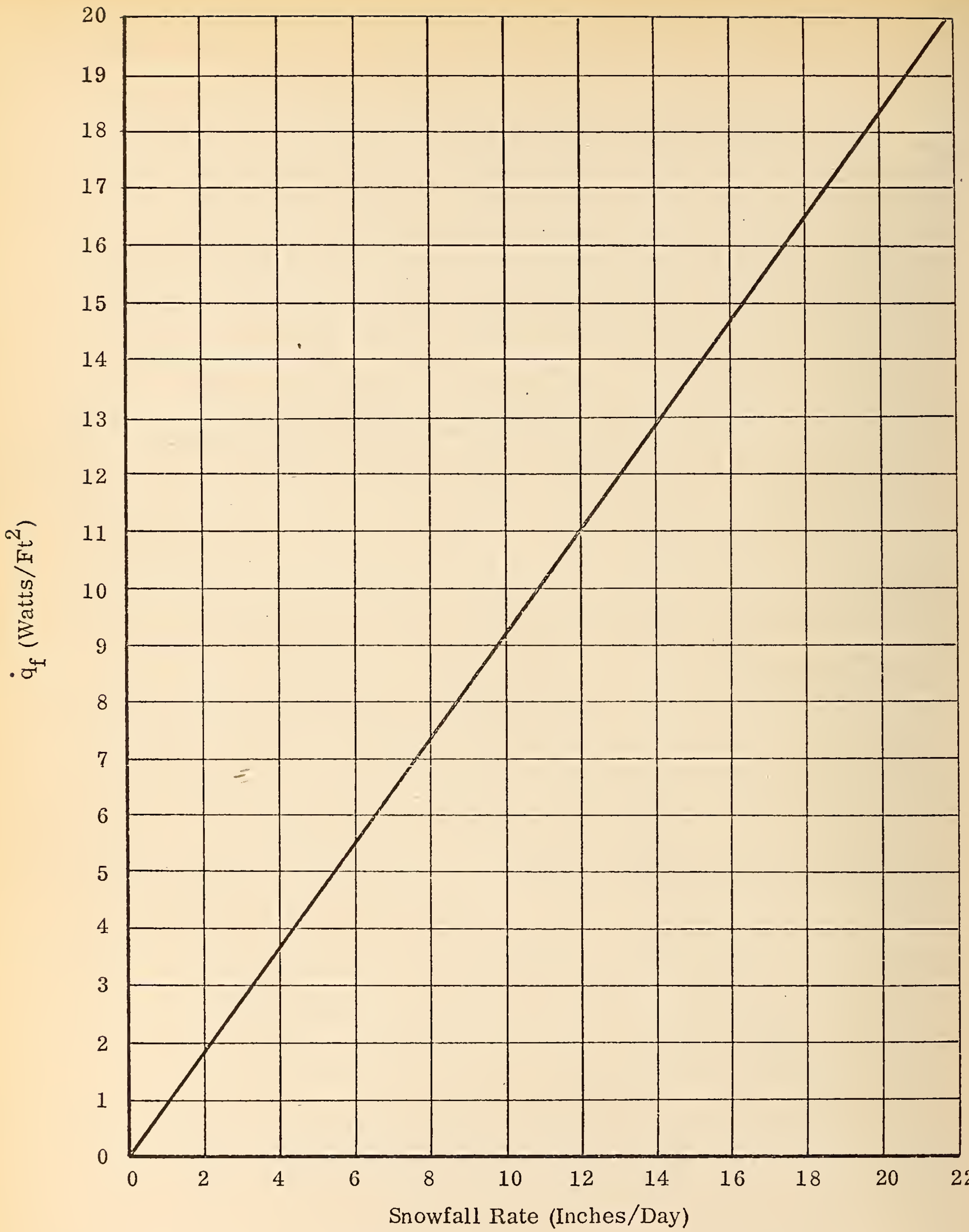


FIGURE VI-4

FUSION LOSSES AS A FUNCTION OF SNOWFALL RATE

$\dot{r} = 6$ inches/day (average 24-hour snowfall)

$n = 1.0$ (sky is completely overcast)

The procedure to be followed for determining the surface heat flux is:

- Determine the temperature difference between the pavement surface and ambient:

  $$T_s - T_a = 32 - 25 = 7^{o}F$$

- Determine the convection heat loss using Figure VI-1:

  $$q_{cv} = 5.2 \text{ watts/ft}^2$$

- Determine the radiation heat loss using Figure VI-2:

  $$\dot{q}_r = 1.3 \text{ watts/ft}^2$$

- Calculate the vapor pressure difference between the pavement surface and the atmosphere. The saturation vapor pressure as a function of air temperature is given in Table B.1 (Appendix B). The vapor pressure at the surface of the pavement ($p_{v,w}$) is determined directly from Table B.1. The atmospheric vapor pressure ($p_{v,a}$) for the associated air temperature and relative humidity (R.H.) is determined using:

  $$p_{v,a} = p_g \text{ (R.H.)} \qquad \text{VI-6}$$

  where p_g is the saturation pressure at ambient temperature. Again, p_g can be determined directly from Table B.1.

  Using this procedure, the calculation for the vapor pressure difference is:

  $$p_g = 0.130 \text{ inches Hg (Table B.1 at } 25^{o}\text{F air)}$$

$$p_{v,a} = (0.130)(0.65) = 0.0845 \text{ inches Hg (Equation VI-6)}$$

$$p_{v,w} = 0.180 \text{ inches Hg (Table B.1 at } 32^{\circ}\text{F pavement surface temperature)}$$

$$p_{v,w} - p_{v,a} = 0.180 - 0.0845 = 0.0955 \text{ inches Hg}$$

- Using the calculated vapor pressure difference, enter Figure VI-3 and determine the evaporation heat loss:

$$\dot{q}_e = 4.7 \text{ watts/ft}^2$$

- The fusion heat loss (due to snow melting) is determined using Figure VI-4:

$$\dot{q}_f = 5.5 \text{ watts/ft}^2$$

- Sum the heat losses (surface heat flux) using Equation VI-5:

$$\dot{q}_s = 5.2 + 1.3 + 4.7 + 5.5 = 16.7 \text{ watts/ft}^2$$

The surface heat flux calculated in Example VI-1 is that required to maintain a "bare pavement" during the specified environmental conditions. The net thermal losses from the pavement system must consider the heat contribution from the ground and the heat content of the pavement itself. Therefore, the pavement heating system can be designed to deliver less than 16.7 watts/ft^2 (Example VI-1).

At any location, the climatic conditions will vary considerably during the winter season. The highway engineer must decide whether he wants to design a system which will maintain "bare pavement" conditions under the most severe winter environment encountered at a particular location or whether his criteria is to prevent ice formation for an average winter environment. The choice is an economic trade-off.

The highway engineer is directed to weather data for the location of interest which is published by the United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (Local Climatological Data: Annual Summary). The following procedure is recommended for obtaining average and severe climate data:

- Select data from the section that gives the normals, means, and extremes which have been compiled over a number of years (see Appendix B for Baltimore weather data).

- Select from the most severe winter month (usually January) the following data to obtain average design conditions:

    - Average daily temperature
    - Average wind speed
    - Average relative humidity
    - One-third of the maximum monthly snowfall

- Select from the same month the following data to obtain severe design conditions:

    - Minimum daily temperature
    - Average wind speed
    - Average relative humidity
    - One-third of the maximum monthly snowfall

- Follow the procedure outlined in Example VI-1 to obtain the thermal losses and the required surface heat flux to maintain a "bare pavement".

This procedure was followed to obtain the data shown in Table VI-1. The required surface heat fluxes vary from 7.8 watts/ft^2 for average weather conditions for Baltimore, Maryland, to 42.0 watts/ft^2 for severe weather conditions for Binghamton, New York.

B. Design Procedure for an Earth Heat Pipe Slab

In the design of an actively heated concrete slab, it is essential to understand the thermal relationships existing between the heat pipe source, the ground, the concrete slab, and the ambient environment. Since the melting capability of a heat pipe system is of utmost importance, it is necessary to express the heat flux delivered to the concrete's surface as a function of the basic system parameters. This surface flux, in conjunction with the concrete surface temperature, will determine the heat available for snow melting under specified ambient conditions. The surface heat flux is comprised of the heat pipe flux, the ground contribution, and the sensible heat loss of the concrete. When these flux components are defined as a function of system parameters and ground source temperature, an active heating system can be chosen to fulfill the surface flux requirements.

By ignoring the influence of ground heat flux, the heat balance governing the concrete slabs behavior can be easily expressed. The heat flux supplied by the heat pipe must be conducted to the surface or absorbed by the concrete. For an earth heat pipe slab, assuming the variation of heat pipe temperature with time is representative of the average slab temperature's variation with time, this heat balance can be written:

$$\frac{1}{R_{p-g}} (T_g - T_{hp}) = \frac{1}{R_{p-s}} (T_{hp} - T_s) + Mc_p \frac{dT_{hp}}{dT} \qquad \text{VI-7}$$

Location	Average Annual Temperature (^{o}F)	Daily Temperature (^{o}F)		Average Wind Speed (mph)	Average Relative Humidity (%)	1/3 of Max. Monthly Snowfall (inches/day)	Required Surface Heat Flux (Watts/Ft^2)	
		Average	Minimum				Average	Severe
Baltimore	55.2	34.8	25.3	10.1	65	7.1	7.8	23.3
Cincinnati	53.4	31.6	22.7	10.8	70	5.1	10.8	26.0
Indianapolis	52.1	29.1	21.0	11.1	74	5.7	15.4	29.4
Boston	51.4	29.9	23.0	14.6	63	10.8	22.6	37.0
Chicago	50.8	26.0	19.0	11.5	67	9.6	25.8	38.1
Denver	49.5	28.5	14.8	9.3	54	7.9	19.5	38.6
Concord	45.6	21.2	10.6	7.3	66	11.1	28.5	40.9
Binghamton	45.8	23.8	17.4	11.7	78	12.2	30.9	42.0

TABLE VI-1

SUMMARY OF JANUARY CLIMATIC CONDITIONS FOR VARIOUS CITIES AND THE CORRESPONDING STEADY-STATE SURFACE HEAT FLUXES REQUIRED TO ACHIEVE A "BARE PAVEMENT" UNDER AVERAGE AND SEVERE WEATHER CONDITIONS

T_{hp} = Temperature of the heat pipe (^{o}F)

T_g = Ground source temperature (^{o}F)

T_s = Concrete surface temperature (^{o}F)

M = Mass of concrete per unit area (107.25 lb/ft^2)

C_p = Specific heat of concrete (0.0457 watt-hr/lb-^{o}F)

R_{p-s} = Resistance from heat pipe to surface (^{o}F-ft^2/watt)

R_{p-g} = Resistance from heat pipe to ground (^{o}F-ft^2/watt)

The total resistance from the heat pipe to the ground has been determined experimentally from tests conducted at the Fairbank Test Site. For one inch diameter heat pipes extending into the ground 40 feet, R_{p-g} was determined to be 0.081^{o}F/watt. R_{p-g} for heat pipes extending 30 feet into the ground was determined to be 0.129^{o}F/watt. The values of R_{p-g} are for the ground composition at the Fairbank Test Site and, although they are considered representative, they will vary somewhat from location to location.

In order to use resistances R_{p-s} and R_{p-g} in Equation VI-7, adjustments must be made for the heat pipe spacing in the slab. The resistance from the heat pipe to the pavement surface was determined analytically through the nodal network predictions of heat pipe temperature as a function of heat pipe heat flux (Figure VI-5) for an isothermal surface at 32^{o}F. Note that the heat pipe temperature for a heat pipe heat flux of zero (Figure VI-5) is not 32^{o}F. This is due to the influence of the ground contribution on heat pipe temperature. For this reason, the slope of the curves in this figure cannot be related directly to the difference between heat pipe temperature and a surface temperature of 32^{o}F. To satisfy the condition that $\dot{q}_{hp}$ = 0 at a heat pipe temperature of 33.2^{o}F, the equation used to relate heat pipe temperature to heat pipe flux is:

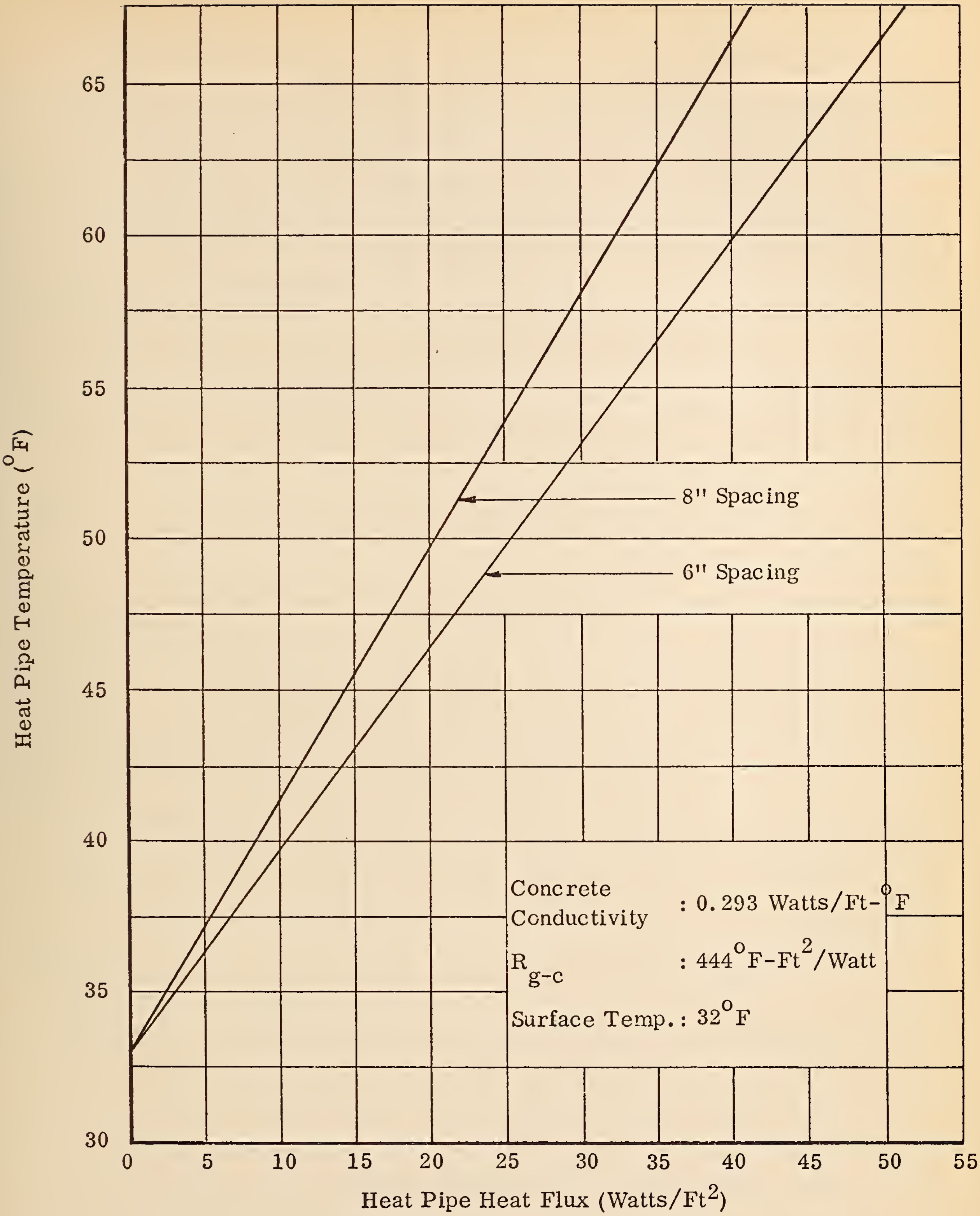


FIGURE VI-5

STEADY-STATE HEAT PIPE TEMPERATURE VS.
HEAT PIPE HEAT FLUX DURING MELTING

$$T_{hp} = R_{p-s}\, \dot{q}_{hp} + (32.0 + 1.2) \qquad \text{VI-8}$$

The adjusted heat pipe to ground resistance and heat pipe to pavement surface resistance are summarized in Table VI-2.

Using Equation VI-7 and the definition of the resistance from the heat pipe to the pavement surface which is:

$$\dot{q}_{hp} = \frac{1}{R_{p-s}} (T_{hp} - 1.2 - T_s) \qquad \text{VI-9}$$

an equation for the steady-state heat pipe heat flux can be obtained.

$$\dot{q}_{hp} = \frac{1}{R_{p-s}} \left(\frac{R_{p-s}\, T_g + R_{p-g}\, (T_s + 1.2)}{R_{p-s} + R_{p-g}} - (T_s + 1.2) \right) \qquad \text{VI-10}$$

Equation VI-10 gives the steady-state heat flux in terms of ground temperature T_g and pavement surface temperature T_s (taken as 32°F when snow melting occurs).

The nodal network model was also used to determine the effects of heat pipe temperature on ground heat contributions. The model was applied for actively heated slabs with 6-inch and 8-inch heat pipe spacings for dry and melting pavement surfaces. The ground contribution for dry pavement surfaces in watts/ft^2 for a 6-inch pipe spacing in the concrete is:

$$\dot{q}_{g-c} = 0.121\, (T_g - T_{hp}) + 0.91 \qquad \text{VI-11}$$

The ground contribution for an 8-inch pipe spacing in the concrete is:

$$\dot{q}_{g-c} = 0.104\, (T_g - T_{hp}) + 1.33 \qquad \text{VI-12}$$

For a wet surface (isothermal at 32°F), these equations cannot be used because of the stabilizing effect of the sink temperature on the heat pipe temperature. Instead, the

CONFIGURATION	R_{p-s} $^{o}F-Ft^2/Watt$	R_{p-g} $^{o}F-Ft^2/Watt$
6-inch spacing, 30 feet deep	0.667	0.774
8-inch spacing, 30 feet deep	0.839	1.032
6-inch spacing, 40 feet deep	0.667	0.486
8-inch spacing, 40 feet deep	0.839	0.648

$MC_p = 4.91$ Watt-Hour/Ft^2-^{o}F

All resistances are based on 12-foot wide pavement

TABLE VI-2

EXPERIMENTALLY DETERMINED HEAT PIPE RESISTANCES

ground heat flux is shown as a function of ground temperature for various heat pipe heat fluxes in Figures VI-6 and VI-7 for 6-inch and 8-inch pipe spacings, respectively.

Through integration of Equation VI-7 and subsequent substitution into Equation VI-9, the surface heat flux due to heat pipe heat flux and sensible heat loss can be defined as a function of time. The resulting equation is:

$$q_{hp} - q_{sh} = \frac{1}{R_{p-s}} \left[\left(T_{hpi} - \frac{R_{p-s} T_g + R_{p-g} (T_s + 1.2)}{R_{p-s} + R_{p-g}} \right) e^{- \frac{1}{Mc_p} \left(\frac{R_{p-s} + R_{p-g}}{R_{p-s} R_{p-g}} \right) t} + \frac{R_{p-s} T_g + R_{p-g} (T_s + 1.2)}{R_{p-s} + R_{p-g}} - (T_s + 1.2) \right] \qquad \text{VI-13}$$

where T_{hpi} is the initial temperature prior to snow melting. This equation is only valid for constant ground and concrete surface temperatures. However, Equation VI-13 can be utilized to determine the surface heat flux delivered during the transient adjustment of the slab from a steady-state dry condition to a steady-state melting condition. The magnitude of this flux is naturally dependent on the initial condition of the slab. The response time of the system is dependent on the concrete mass and the resistance of the heat pipe to the surface and to the ground. For all the system configurations considered, the slab nearly reaches an equilibrium wet condition after 6 hours. For this reason, the surface heat flux defined by Equation VI-13 can be integrated over 6 hours to obtain an average surface flux associated with the transient adjustment period. The average surface heat flux during the 6-hour transient period (contribution of the heat pipe and sensible heat loss of the concrete) is given in Figures VI-8, VI-9, VI-10, and VI-11. The data is presented for various ground temperatures, various initial heat pipe temperatures, 6 and 8-inch pipe spacings in the pavement, and for heat pipes buried 30 and 40 feet in the ground.

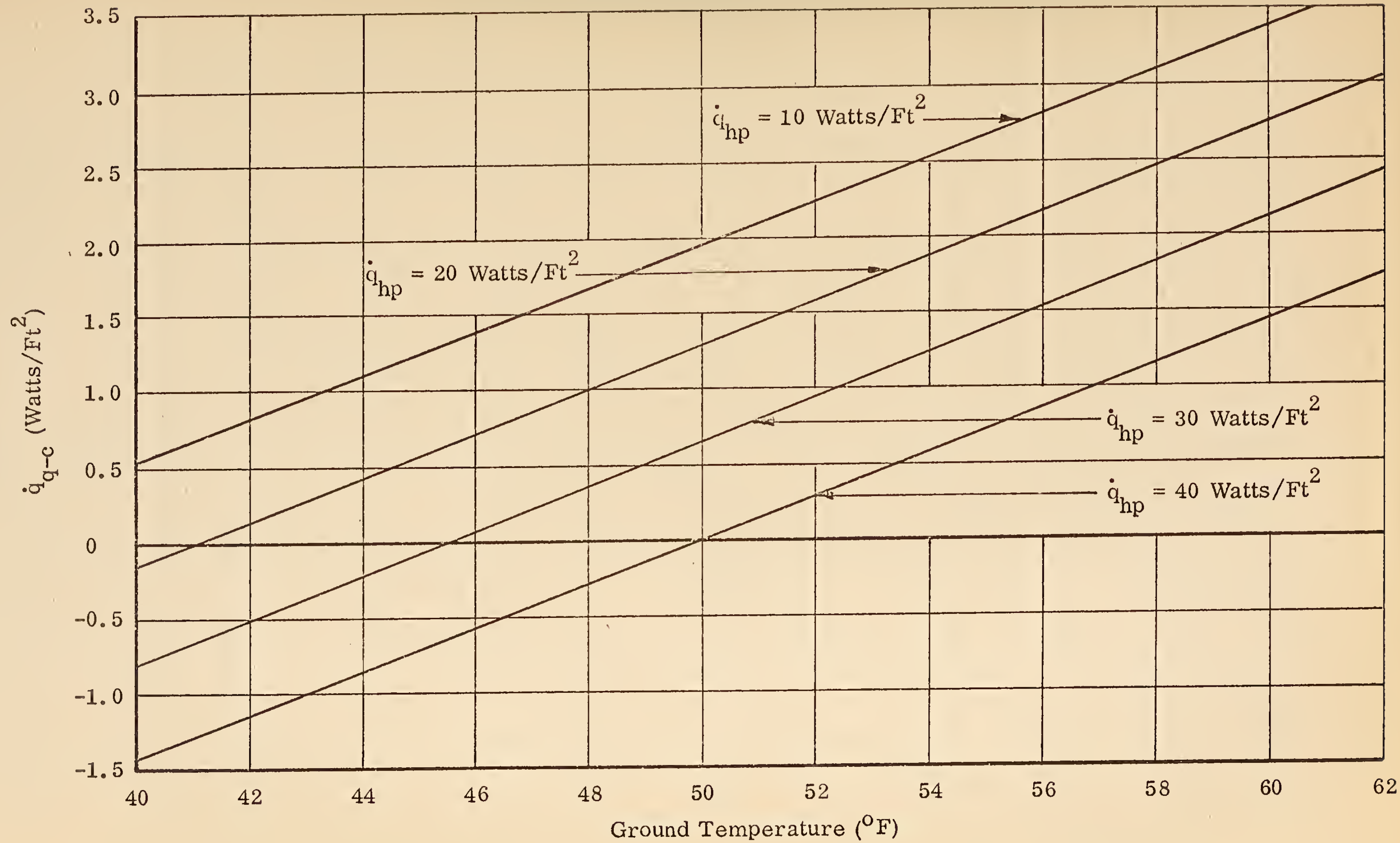


FIGURE VI-6

WET-SURFACE STEADY-STATE GROUND CONTRIBUTION
FOR 6-INCH HEAT PIPE SPACING IN PAVEMENT

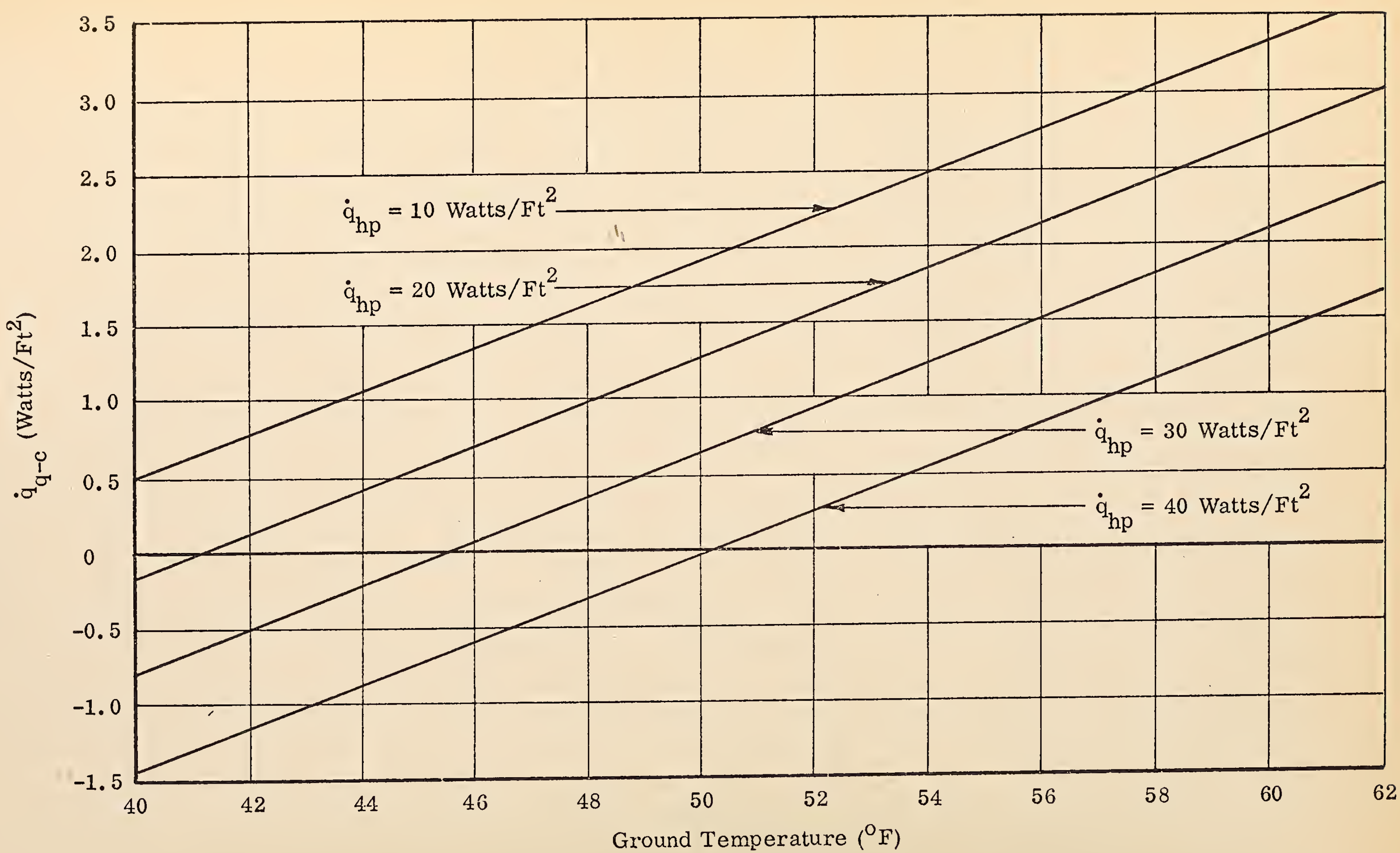


FIGURE VI-7

WET-SURFACE STEADY-STATE GROUND CONTRIBUTION
FOR 8-INCH HEAT PIPE SPACING IN PAVEMENT

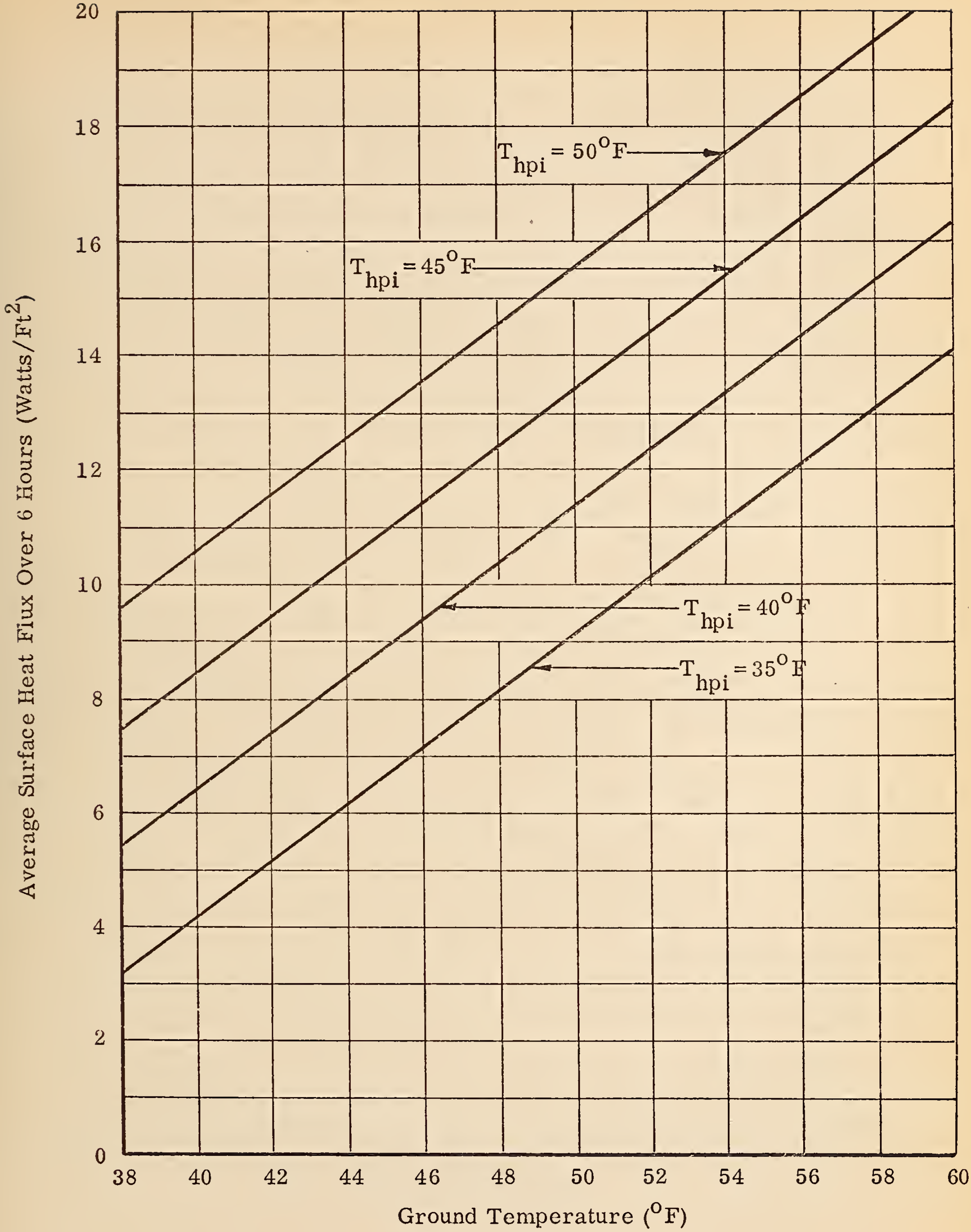


FIGURE VI-8

AVERAGE SURFACE HEAT FLUX DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 6-INCH SPACING AND 30 FEET IN THE GROUND

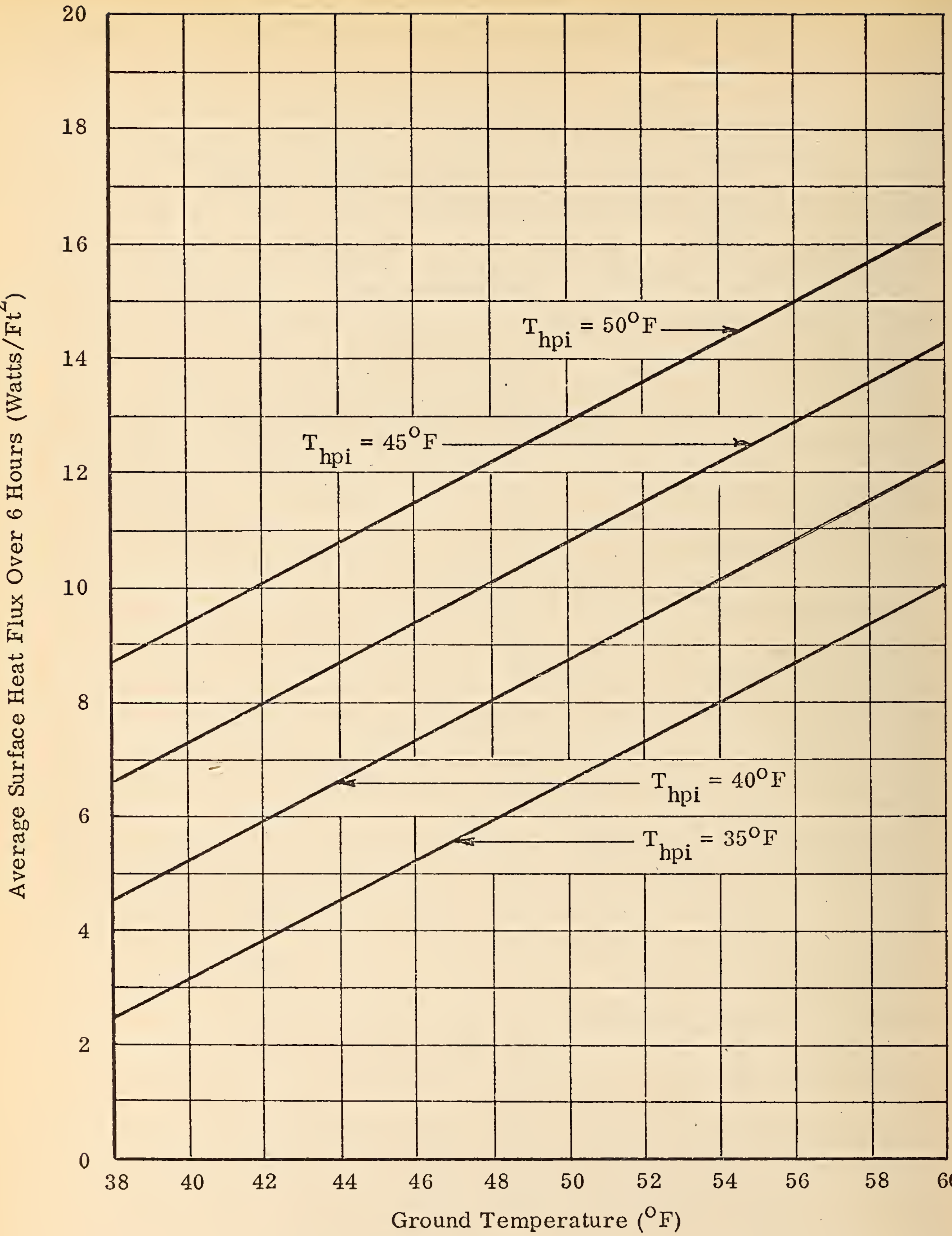


FIGURE VI-9

AVERAGE SURFACE HEAT FLUX DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 8-INCH SPACING AND 30 FEET IN THE GROUND

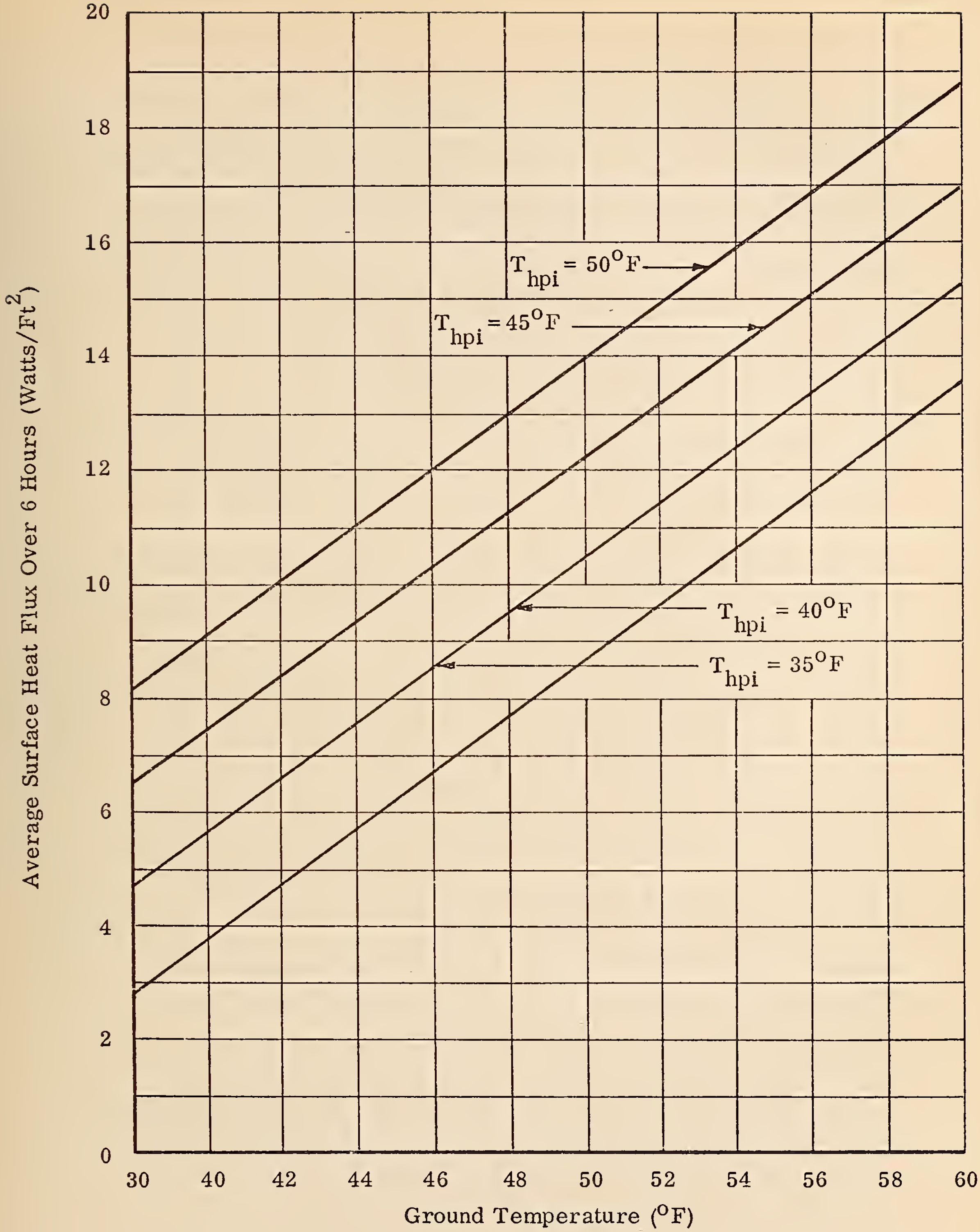


FIGURE VI-10

AVERAGE SURFACE HEAT FLUX DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 8-INCH SPACING AND 40 FEET IN THE GROUND

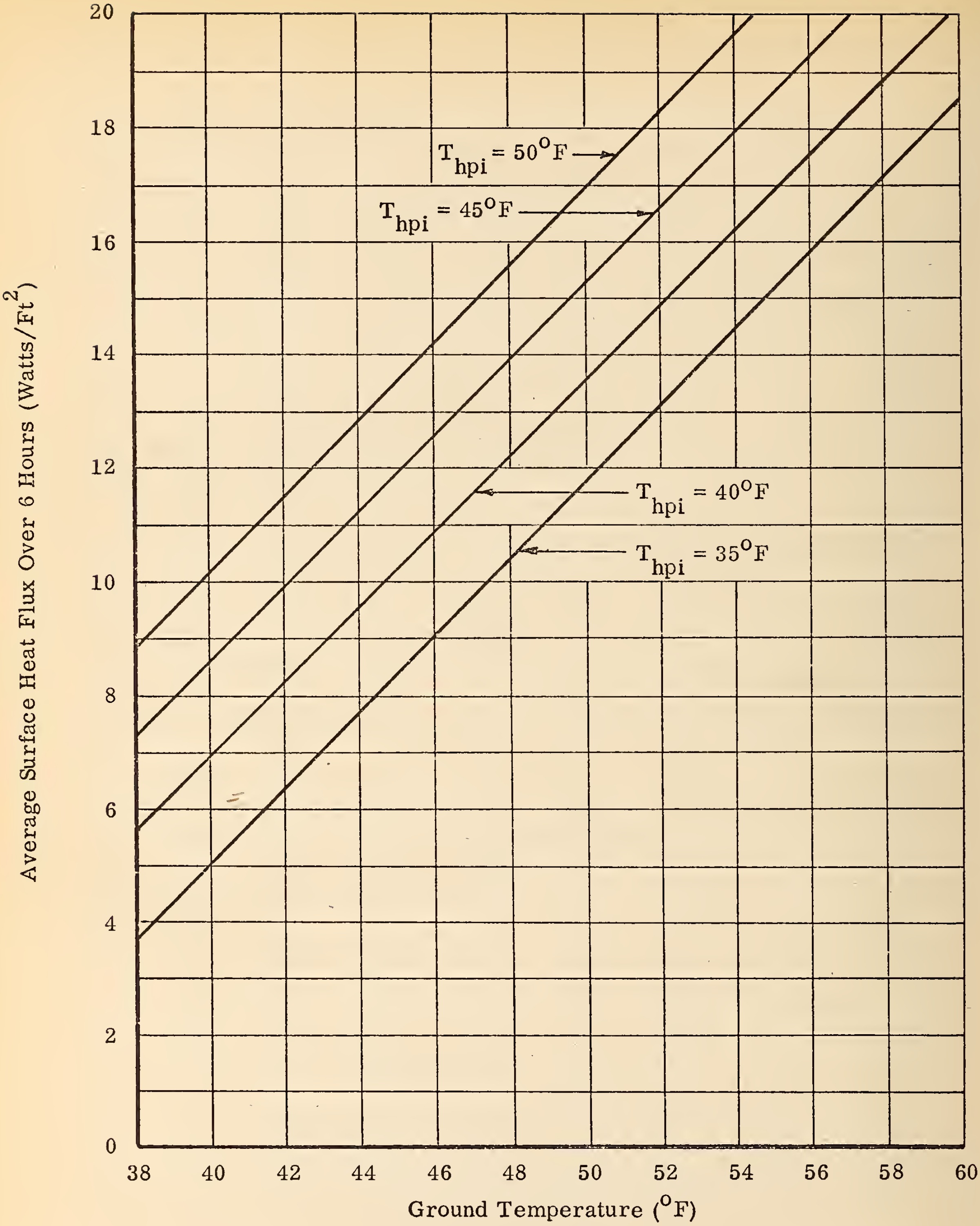


FIGURE VI-11

AVERAGE SURFACE HEAT FLUX DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 6-INCH SPACING AND 40 FEET IN THE GROUND

The component of the pavement surface heat flux associated with the ground contribution can be found by averaging the ground flux occurring initially for a dry surface (Equations VI-11 and VI-12) and the ground flux associated with the wet steady-state condition (Figures VI-6 and VI-7).

The basic design procedure for calculating the design of an earth heat pipe system is as follows:

- Determine the ambient losses associated with convection, radiation, and evaporation at a pavement surface temperature of $32^{\circ}F$ (snow melting) and at the ambient conditions selected for the specified location (see Section VI-A).

- Select a design configuration (heat pipe spacing and heat pipe depth in the ground).

- Determine the steady-state heat pipe heat flux and the associated ground heat input (Equation VI-10, Figures VI-6 and VI-7).

- Compare the steady-state pavement surface heat flux with the ambient losses to determine the melt rate capability of the heating system during steady-state.

- Determine the initial heat pipe temperature T_{hpi} that satisfies the heat balance defined by the dry steady-state ambient conditions.

- Calculate the average surface heat flux available during the transient adjustment period of the system (adjustment from dry to wet surface conditions), and compare this value to the ambient losses calculated initially to determine the melt rate capability during the transient period.

- If necessary, adjust the design configuration initially selected so that the specified melt rate is achieved. If the melt rate cannot be achieved by design, an augmented system is required.

To illustrate the design procedure and the use of the figures and equations developed herein, Example VI-2 is given:

<u>Example VI-2</u>

Consider a 12-foot wide ramp pavement in a given location and containing heat pipes on 6-inch spacing and buried 30 feet in the ground. The ambient conditions for the location during a snowfall are:

$$T_g = 56^{\circ}F$$

$$T_a = 25^{\circ}F$$

$$R.H. = 65\%$$

$$v = 5 \text{ mph}$$

Determine the snow melting capability of this system.

Assume that the concrete surface is initially above $32^{\circ}F$ and, therefore, the addition of snow will isothermalize the surface at approximately $32^{\circ}F$. The convective, radiative, and evaporation heat losses at the surface temperature of $32^{\circ}F$ can be obtained from Figures VI-1, VI-2, and VI-3, respectively, and are:

$$\dot{q}_{cv} = 5.2 \text{ watts/ft}^2$$

$$\dot{q}_r = 1.3 \text{ watts/ft}^2$$

$$\dot{q}_e = 4.7 \text{ watts/ft}^2$$

The total heat loss is 11.2 watts/ft^2.

For the chosen system design, the steady-state pavement surface heat flux associated with the heat pipe can be obtained from Equation VI-10. For a surface temperature of $32^{o}F$, this equation yields a steady-state heat pipe heat flux of 15.8 watts/ft^2. The ground contribution associated with this heat pipe heat flux is obtained from Figure VI-6 and is 2.5 watts/ft^2. The total available pavement surface heat flux is the sum of these two values or 18.3 watts/ft^2.

The ambient losses determined above were 11.2 watts/ft^2; therefore, the pavement surface heat flux available for melting snow is 18.3 - 11.2 or 7.1 watts/ft^2. Using Figure VI-4, the snow melting capability of the system is 7.8 inches/day for the environmental conditions. During the first 6 hours of snowfall, the melting capability may be higher than this value. The environmental history prior to snowfall is an important factor in determining the transient melting capability of the pavement heating system.

Assume that the pavement was exposed to the following ambient conditions for a period long enough to achieve equilibrium.

$$T_g = 56^{o}F$$

$$T_a = 35^{o}F$$

$$v = 5 \text{ mph}$$

There exists a unique initial heat pipe temperature T_{hpi} that satisfies the heat balance of a dry pavement surface (the sum of the heat pipe flux and the ground contribution must equal the ambient losses or $\dot{q}_{loss} = \dot{q}_{g-c} + \dot{q}_{hp}$). The value for $\dot{q}_{hp}$ is defined by:

$$\dot{q}_{hp} = \frac{1}{R_{p-g}} (T_g - T_{hp}) \qquad \text{VI-14}$$

The value for $\dot{q}_{g-c}$ is given by Equation VI-11. The solution for the initial heat pipe temperature must be obtained through iteration. The procedure is to select a arbitrary heat pipe temperature and calculate the value of $\dot{q}_s$ using Equations VI-11 and VI-14. This surface heat flux is then compared to the calculated loss from a dry pavement using Equation VI-9 to obtain the pavement surface temperature T_s and then using Figures VI-1 and VI-2 to calculate $\dot{q}_{loss}$. To achieve a heat balance, $\dot{q}_s$ must equal $\dot{q}_{loss}$. Using this procedure, an initial heat pipe temperature of 50.6^{o}F is found to satisfy the heat balance.

Turn to Figure VI-8. The ground temperature is defined as 56^{o}F and the initial heat pipe temperature T_{hpi} was determined to be 50.6^{o}F. For this conditions, the average surface heat flux over the first six hours of snowfall (Figure VI-8) is 18.7 watts/ft^2.

The ground contribution during the transient period can be assumed as the average of the ground contributions corresponding to the dry steady-state condition and the melting steady-state condition. The total average surface heat flux during the first 6 hours of snowfall, including this ground contribution is 20.7 watts/ft^2.

The ambient losses were previously determined to be 11.2 watts/ft^2; and, therefore, the pavement surface heat flux available during the first 6 hours for snow melting is 20.7 - 11.2 = 9.5 watts/ft^2. This heat flux is capable of melting 10.5 inches/day of snow. This melt rate compares to the equilibrium melt rate of 7.8 inches/day calculated previously.

Example VI-3

The transient surface heat flux depends on the ambient temperature history prior to snowfall. Consider the situation where the pavement has been exposed to an air temperature of $25^{o}F$ at a wind speed of 5 mph for a sufficient time to reach equilibrium. The initial heat pipe temperature T_{hpi} decreases from $50.6^{o}F$ (Example VI-2) to $47.8^{o}F$. The average transient pavement heat flux associated with this heat pipe temperature is 17.5 watts/ft^2. Adding to this the ground contribution, the value becomes 19.7 watts/ft^2. Subtracting the ambient losses of 11.2 watts/ft^2 previously calculated, the heat flux available for snow melting is 8.5 watts/ft^2 which is equivalent to a melting capability of 9.3 inches/day over the initial 6-hour period. This melt rate is still in excess of the equilibrium melt rate of 7.8 inches/day calculated previously.

The highway engineer can use this procedure to investigate the effects of local weather conditions on the snow melting capability of the pavement heating system. A study has been made of the average size of snow storms in 12 representative locations randomly chosen across the United States (Reference 6). The study yielded an estimated snowfall of 1.5 inches as being the average for those days when a storm occurred. This size storm is within the transient capability of the heat pipe pavement heating system.

C. Design Procedure for an Electrical Heat Pipe Slab

The design of an electrically-powered heat pipe slab is comparatively simple because the heat pipe flux is not limited by heat pipe temperature. However, the design approach is comparable to that used for an earth heat pipe slab. The system performance during a wet surface steady-state condition can still be used as the determining factor in system design, although the increase in available surface flux during transient system adjustment is usually more notable because of the constant heat pipe flux.

As for the earth heat pipe slab, the heat balance governing the electrical slab's behavior can be expressed in the absence of ground heat inputs. Assuming the time variation of heat pipe temperature is equal to the time variation in average slab temperature, this heat balance can be written:

$$\dot{q}_{hp} = \frac{1}{R_{p-s}} (T_{hp} - (T_s + 1.2)) + Mc_p \frac{dT_{hp}}{dt} \qquad \text{VI-15}$$

The resistance from the heat pipe to the concrete surface and the thermal compacitance have previously been given in Table VI-2. Integrating Equation VI-15 yields a relationship for heat pipe temperature as a function of time which, when substituted into Equation VI-9, results in an equation for the surface flux due to the heat pipe flux and the concrete's sensible heat loss.

$$\dot{q}_{hp} + \dot{q}_{sh} = \frac{1}{R_{p-s}} \left[\left(T_{hpi} - R_{p-s}\, \dot{q}_{hp} - (T_s + 1.2) \right) e^{-\frac{1}{Mc_p R_{p-s}} t} + R_{p-s}\, \dot{q}_{hp} \right] \qquad \text{VI-16}$$

This equation is valid only for constant concrete surface temperature. If this equation is integrated over a time period of six hours, the average surface flux during the transient adjustment of the slab from a dry to a wet thermal distribution can be found. This

average surface flux (exclusive of the component due to ground heat inputs) is shown in Figures VI-12 and VI-13 as a function of heat pipe flux, with initial heat pipe temperature as a parameter and for heat pipe spacings of 6 inches and 8 inches respectively. Note that some sections of the curves indicate a transient average surface flux. These sections of the curves are representative for an initial dry condition at which the surface temperature is below $32^{\circ}F$. Upon snow accumulation, the surface will become insulated and the surface temperature increases to $32^{\circ}F$ at which point melting starts. Thus, part of the heat pipe flux is converted into sensible heat of the concrete. This explains the difference between heat pipe and surface flux. The surface flux due to ground contributions can be found by averaging the dry surface ground heat input given by Equations VI-11 or VI-12 and the wet surface ground heat input shown in Figures VI-6 or VI-7.

The design procedure for an electrical heat pipe slab is similar to that for an earth heat pipe slab. First, assuming a surface temperature of $32^{\circ}F$, it is necessary to determine the ambient losses. The heat of fusion associated with the melt rate requirements are then added to the ambient losses to determine the required steady-state surface flux which the system must supply. Then, choosing the heat pipe spacing, the heat pipe flux and associated ground heat inputs can be determined through iteration to provide the required surface flux. Now, the transient system behavior must be determined. The initial heat pipe temperature which satisfies the heat balance defined by the dry steady-state ambient conditions must be determined. Then, the average surface flux available during the transient slab adjustment to the wet steady-state conditions can be calculated. Comparing this average transient surface flux to the ambient losses related to a surface temperature of $32^{\circ}F$, the transient melt rate capability can then be determined.

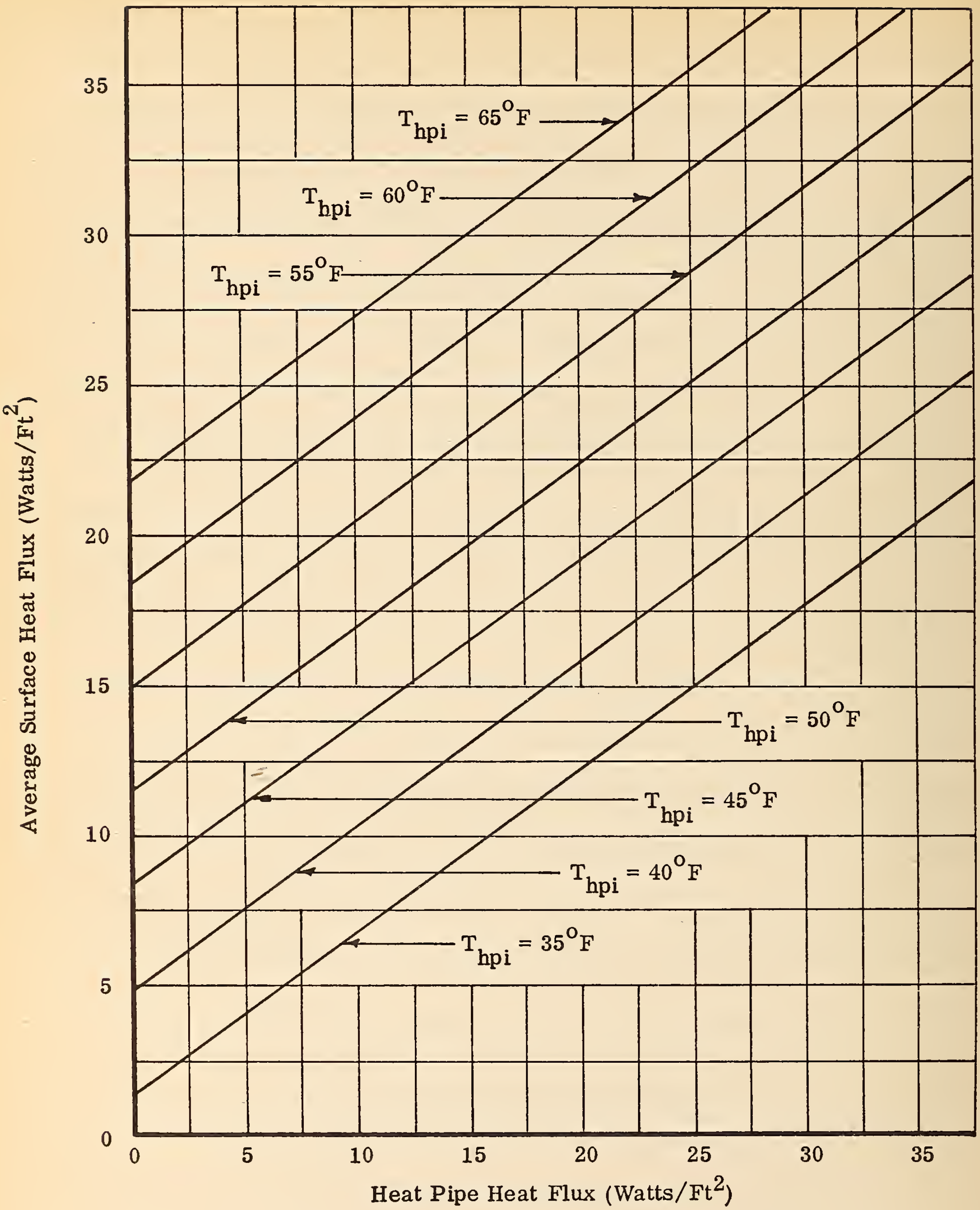


FIGURE VI-12

AVERAGE HEAT FLUX ON ELECTRICAL SLAB PAVEMENT DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 6-INCH SPACING

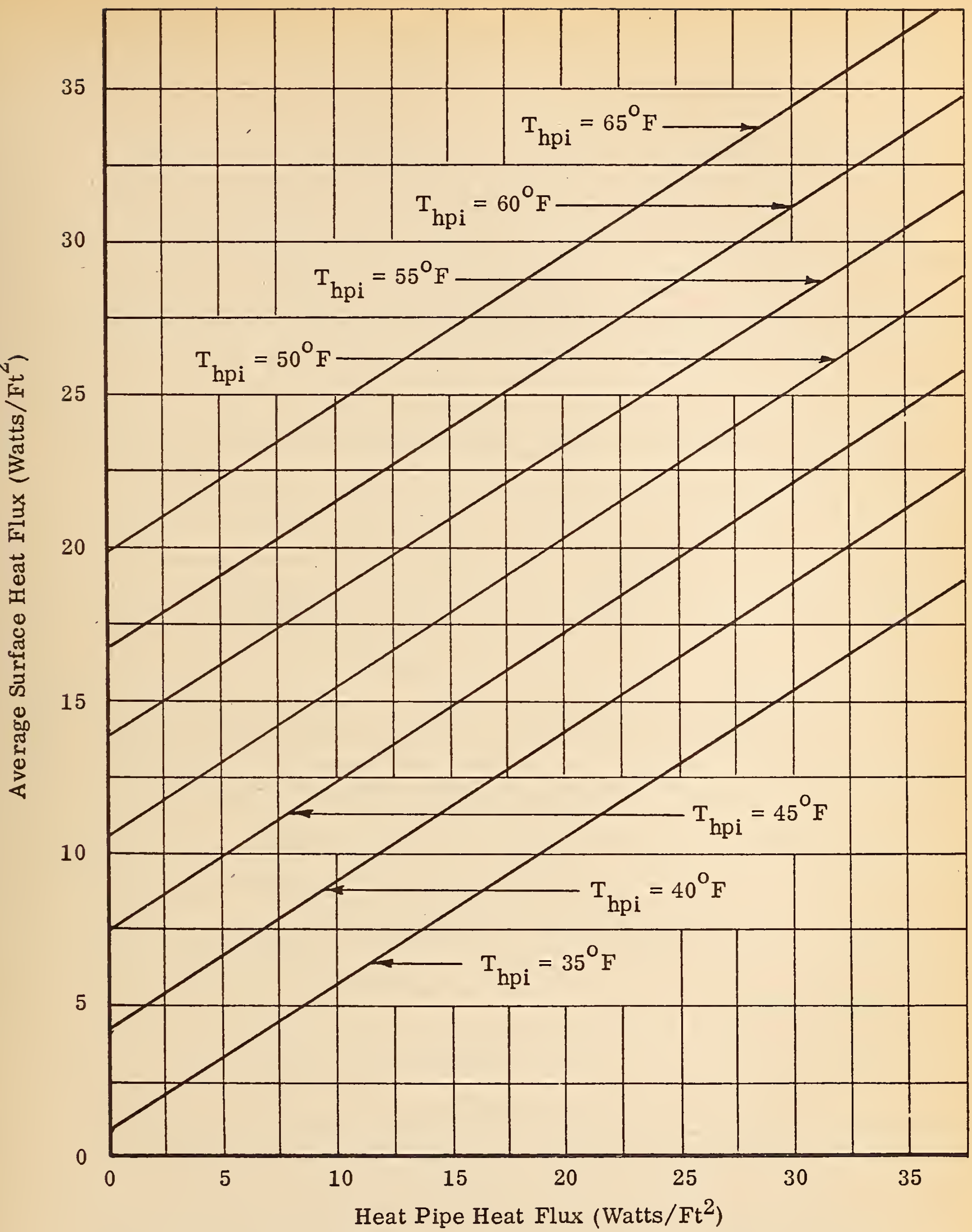


FIGURE VI-13

AVERAGE HEAT FLUX ON ELECTRICAL SLAB PAVEMENT DURING FIRST 6 HOURS OF TRANSIENT BEHAVIOR FOR PIPES ON 8-INCH SPACING

Example VI-4

To exemplify the design procedure for an electrical heat pipe slab, consider the requirements specified in Example VI-2 given previously.

$$T_g = 56^{\circ}F$$

$$T_a = 25^{\circ}F$$

$$R.H. = 65\%$$

$$v = 5 \text{ mph}$$

Again, assume the system design consists of heat pipes with 12-foot condensers and are placed 6 inches apart within the slab. For comparative purposes, assume the system is required to melt 7.8 inches of snow per day which is the melting capability of the previously considered earth heat pipe system design. Since the system requirements are the same as before, the required surface flux during the steady-state wet condition is 18.3 watts/ft^2. To provide this surface flux, the heat pipe flux must be 15.8 watts/ft^2 since the ground contribution is 2.5 watts/ft^2.

Now it becomes necessary to evaluate the transient behavior of the system. Assume the slab has adjusted to the same initial conditions as in Example VI-2:

$$T_g = 56^{\circ}F$$

$$T_a = 35^{\circ}F$$

$$v = 5 \text{ mph}$$

Associated with these ambient conditions and a constant heat pipe flux, the initial heat pipe temperature must satisfy the heat balance for a dry surface, hence:

$$\dot{q}_{loss} = \dot{q}_{g-c} + \dot{q}_{hp}$$

$$\dot{q}_{hp} = 15.8 \text{ watts/ft}^2$$

$$T_s = T_{hp} - R_{p-s}\, q_{hp} - 1.2 \qquad \text{VI-9}$$

$$\dot{q}_{g-c} = 0.120\,(T_g - T_{hp}) + 0.91 \qquad \text{VI-11}$$

$$\dot{q}_{loss} = f\,(T_s)$$

The initial heat pipe temperature must be obtained through iteration.

Assume: $T_{hpi} = 60^{o}F$

Therefore: $\dot{q}_{g-c} = 0.43 \text{ watts/ft}^2$

$T_s = 48.2^{o}F$

$\dot{q}_{loss} = 11.2 \text{ watts/ft}^2$

$\dot{q}_s = 16.2 \text{ watts/ft}^2$

Since ambient losses are less than the available surface flux the assumption on initial heat pipe temperature is too low.

Assume: $T_{hpi} = 65.5^{o}F$

Therefore: $\dot{q}_{g-c} = -0.2 \text{ watts/ft}^2$

$T_s = 53.7^{o}F$

$\dot{q}_{loss} = 15.6 \text{ watts/ft}^2$

$\dot{q}_s = 15.6 \text{ watts/ft}^2$

This assumption on initial heat pipe temperature is very near the actual heat pipe temperature that would exist for a dry surface in equilibrium with the specified ambient conditions. Figure VI-12 yields, by extrapolation, for

q_{hp} = 15.8 watts/ft^2 and t_{hpi} = 65.5^{o}F a transient surface flux of 30.4 watts/ft^2. The average ground heat input during the transient period is 1.2 watts/ft^2. Thus, the average total surface flux during the first 6 hours of the transient period is 31.6 watts/ft^2. Subtracting the losses associated with a wet slab whose surface is isothermal at 32^{o}F, the heat flux available for melting is 20.4 watts/ft^2.

Example VI-5

To illustrate the effect of initial ambient conditions on the average surface flux available during transience, suppose the initial conditions were the same as those in Example II-3, i.e.:

$$T_a = 25^{o}F$$

$$v = 5 \text{ mph}$$

If the steady-state wet surface heat flux requirements remain unchanged, the necessary heat pipe flux is 15.8 watts/ft^2. However, the initial heat pipe temperature which satisfies the heat balance associated with a dry surface is 56.7^{o}F. The surface flux obtained for this initial heat pipe temperature for a heat pipe flux of 15.8 watts/ft^2 (Figure VI-12) is 24.6 watts/ft^2. Adding the surface flux component due to the ground heat input, the average total surface flux during transience is 25.8 watts/ft^2. The heat flux available for melting is 14.6 watts/ft^2.

A comparison of the electrical heat pipe slab and the earth heat pipe slab is summarized in Table VI-3. The earth heat pipe design configuration performs as well as an electrical slab with the same heat pipe spacing and

Condition	Earth Heat Pipe Slab (Pipes, 30' Deep)	Electrical Heat Pipe Slab (15.8 W/Ft^2)
Steady-State Surface Heat Flux Available for Melting (Watts/Ft^2)	7.1	7.1
Average Surface Heat Flux Available for Melting During First 6 Hours (Watts/Ft^2)	9.5*	20.4*
Average Surface Heat Flux Available for Melting During First 6 Hours (Watts/Ft^2)	8.4**	14.6**

*Stable Conditions Prior to Melting : $T_a = 35^\circ F$, $v = 5$ mph
**Stable Conditions Prior to Melting : $T_a = 25^\circ F$, $v = 5$ mph

<u>Assumptions</u>

Ground Temperature	:	$56^\circ F$
Ground-Concrete Conductance	:	$444^\circ F\text{-}Ft^2/Watt$
Heat Pipe Spacing	:	6 inches
Width of Pavement	:	12 feet

Ambient Conditions During Melting	T_a	:	$25^\circ F$
	v	:	5 mph
	R.H.	:	65%

TABLE VI-3

COMPARISON OF TRANSIENT PERFORMANCE OF EARTH AND ELECTRICALLY HEATED PAVEMENTS

and condenser length, after an equilibrium condition associated with surface melting is attained. However, for both cases of initial steady-state dry conditions, the transient surface flux for the electrical slab is greater than the earth slab transient flux because the heat pipe flux for the electrical slab is constant.

D. Other Considerations

The technical feasibility of using earth heat in combination with heat pipes for deicing and removing snow from pavement surfaces has been demonstrated (in the Baltimore/Washington climate) during testing, reported herein, over a span of two winter seasons. The methods to be used for specifying the heating requirements and establishing the steady-state and transient performance capabilities of earth and electrical heat pipe systems have been outlined. When the State highway engineer considers applying earth pavement heating technology to specific field situations, the following additional factors must be evaluated:

- Required volume of earth (ft^3) to be thermally coupled to each square foot of pavement surface. This determines the pipe spacing and depth of pipes in the earth.
- Center-line spacing of heat pipes in the pavement.
- Amount of concrete cover over heat pipes in the pavement.
- Heat pipe placement in the pavement and in the earth.
- The economics of pavement heating systems for specific locations.

Pavement heating systems using earth heat are practical for mild and moderate climates. For severe climates, these systems must be augmented by other sources of thermal energy in order to perform the deicing and snow removal function. Generally, cities which fall within these climate definitions are:

Type Climate	City	Average Annual Temperature
Mild	Dallas, Texas	65.8°F
Moderate	Baltimore, Maryland	55.2°F
Severe	Binghamton, New York	45.8°F

Referring to Table VI-1, the first three cities listed are considered to have moderate climates, the last two cities have severe climates, and Boston, Chicago, and Denver are in between these classifications.

There are two aspects of earth heated pavement systems which determine the practicalness of any specific application. The first concerns itself with the ability of this low temperature system to provide the necessary heat flux to deice and melt snow in a given locality. This ability rapidly becomes marginal as the climate becomes more severe, because the heating requirements are increasing at the same time that the potential for providing heat (average earth temperature which is roughly equal to the average annual temperature) is rapidly decreasing.

The second aspect concerns itself with the total amount of energy that must be supplied to the pavement surface during a winter season. It must be remembered that the heat pipe draws energy from the earth when the pavement temperature is lower than the earth temperature. This will occur throughout the Winter. Figure II-1 gives the annual energy dissipation from the pavement surface as a function of the surface temperature for Syracuse, New York (severe climate) and Baltimore, Maryland (moderate climate). For pavement surface temperatures in the mid-forties, Syracuse systems will require about four times more energy than will the Baltimore systems. This means that Syracuse systems will require the coupling of at least four times more earth volume to each square foot of the pavement surface than will the Baltimore systems (assuming that the end-of-season bulk earth temperature in Syracuse is sufficient to provide the necessary driving potential).

Example VI-6

The volume of earth that must be coupled to the pavement surface

determines the minimum heat pipe spacing in the earth adjacent to the roadway. The minimum space can be determined from:

$$\text{Pipe Spacing in Earth} = \sqrt{\frac{\text{Annual Energy Consumption for Each Pipe}}{(\text{Earth Specific Heat})\ (\Delta T_e)\ (\text{Pipe Depth})}} \qquad \text{VI-17}$$

where:

<u>Earth Specific Heat</u> varies between 30 to 40 BTU/Ft^3-^oF depending on moisture content and type of soil or rock.

<u>ΔT_e</u> represents the allowable temperature drop of the bulk earth due to extraction of energy during the winter season.

The annual energy dissipations determined for three cities by integrating daily energy losses for a typical winter season are:

Baltimore	=	8 Kw-Hrs/Ft^2 Surface
Binghamton	=	32 Kw-Hrs/Ft^2 Surface
Syracuse	=	35 Kw-Hrs/Ft^2 Surface

Assuming that average soil conditions and normal moisture contents are encountered in all three locations:

$$\text{Earth Specific Heat} = 35\ \text{BTU/Ft}^3\text{-}^o\text{F}$$

The bulk earth temperatures (undisturbed) are about 46^{o}F for both Binghamton and Syracuse and 55^{o}F for Baltimore. A reasonable assumption for the permissible temperature drops allowable for the winter season resulting from heat extraction are 4^{o}F for Binghamton and Syracuse and 8^{o}F for Baltimore. Using various values of T_g, the effect of these assumptions on the capability of the heating system can be determined by following the procedure outlined in Example VI-2 on Page VI-24.

In order to convert the annual energy dissipation at the pavement surface to an annual value of energy dissipation for each pipe, the pipe spacing and pavement width must be known. For purposes of this example, assume a pipe spacing of 8 inches for Baltimore and 4 inches for Binghamton and Syracuse. Further, assume that the pavement width is 12 feet for all three locations. Therefore, the annual energy consumption for each pipe at each location is:

Baltimore	=	8 x 12 x 8/12	=	64	Kw-Hrs/Pipe
Binghamton	=	32 x 12 x 4/12	=	128	Kw-Hrs/Pipe
Syracuse	=	35 x 12 x 4/12	=	140	Kw-Hrs/Pipe

Converting to the proper units and using Equation VI-17, the heat pipe spacings in the earth for heat pipes 30 feet deep are:

Baltimore	=	5.1 feet
Binghamton	=	10.2 feet
Syracuse	=	10.6 feet

If the pipes were to be placed to a depth of 40 feet instead of 30 feet, the heat pipe spacing in the earth would become:

Baltimore	=	4.4 feet
Binghamton	=	8.8 feet
Syracuse	=	9.2 feet

The reasonableness of these assumptions was confirmed by testing at Fairbank Highway Research Station. The heat pipes were placed on 4-foot centers in the earth. Two depths were explored (30 and 40 feet). Figure II-12 shows the temperature profile in the earth which was taken at time intervals over the span of an entire year.

The average bulk-earth temperature drop was about 8°F and complete temperature recovery was demonstrated.

Heat pipe spacings in the earth which are much beyond 6 feet and depths beyond 40 feet are probably impractical. This, probably more than any other single consideration, limits the application of this technology to mild and moderate climates.

The second factor that must be considered by the State highway engineer is the spacing of the heat pipes in the pavement. The earth heat pipe system is a low temperature system and, as such, does not provide sufficient driving potential at the pavement surface to prevent ridge formation between pipes during very heavy snowfalls. Calculational techniques described in Section II can be used to predict heat flux and temperature distributions at the pavement surface (Figures II-4 and II-5); however, because of practical considerations, the pipe spacing should be determined by the heating requirements. The following heat pipe spacings are recommended for the various climate classifications in which this system may be applied.

	Average Annual Temperature (°F)	Spacing (Inches)
Mild Climates	65	12
Mild Climates	60	10
Moderate Climates	55	8
Severe Climates	50	6
Severe Climates	45	4

The third factor to be considered in the design of heat pipe systems is the amount of concrete cover over the pipes. The cover over the pipes installed in the test slabs at the Fairbank Highway Research Station is $1\frac{1}{4}$ inches. The centerline of the one-inch pipe is approximately two inches below the pavement surface. Increasing the cover over that which was tested will increase the thermal resistance between the pipe and the pavement

surface. It is recommended that the cover be held to under 2 inches for low temperature earth heat pipe systems because the earth heating system will maintain the pavement above freezing temperatures during the entire Winter and freeze-thaw cycling damage will thereby be eliminated. As a consequence, thinner covers than might be normally considered acceptable are adequate for continuously heated pavements.

The fourth factor to be considered concerns the placement of pipes in the pavement and earth. The drilling of the holes for the heat pipes proved to be a problem during the construction of the Fairbank Test Site. Hurricane Agnes caused the ground to become moisture saturated. The drill rig (Figure IV-11), an Intersoll-Rand Drillmaster Model T-4, became mired in the mud. The gross weight of this rig is 48,000 pounds, and the regular tire bearing area is not suitable for soft earth movement. During actual roadway construction, this rig would be moved on the pavement subbase and part of the problem faced at the test site would be avoided.

A second problem encountered at the test site was the presence of gnessic rock. The original drilling rig was abandoned and the T-4 rig was substituted. This rig can apply feed pressures to a maximum of 32,500 pounds and has a bit-rotation speed up to 100 rpm. A single 40-foot hole was drilled in the rock formation in a period of one hour.

There is no question that, using currently available commercial equipment, hole drilling in the quantities required for an earth heat pipe system will be a difficult and expensive operation. Equally, there is no question that, given the commercial incentives, adequate equipment can be developed which is compatible with modern highway construction practices and where drilling costs are a reasonable percentage of other system costs.

Alternate techniques of pipe placement have been investigated. One promising technique for placement in soft soils and sands has been perfected by Raymond International, Inc. Thirty-thousand feet of one-inch heavy walled pipe was placed in sandy soil to depths up to 80 feet at rates of up to one foot per second.

The second aspect of pipe placement concerns the concrete pavement. Appendix C specifies a heat pipe which requires a positive elevation between 1/2 to 20 degrees as measured from the earth end of the pipe. This permits the working fluid which is condensed in the pavement area of the pipe to drain, by gravity, back down into the earth portion of the pipe. This restriction can be eliminated by substituting a heat pipe of alternate design developed by Dynatherm Corporation.

The final factor of interest to the State highway engineer is that of system economics. It is generally conceded that pavement heating systems cannot be applied generally to highways because the costs would be prohibitive. The following are specific areas where heating systems should be considered either because they improve highway safety or highway availability.

- Bridge Decks
- Ramps
- Acceleration and Deceleration Lanes
- Curves
- Steep Hills

Bridge decks and associated ramps which comprise interchanges are capital intensive installations which are more difficult to clear of snow and ice than are straight sections of highway. Acceleration and deceleration lanes, curves, and steep hills represent decision points for the motorist and potential areas of misjudgment even when not com-

pounded with the problems of ice and snow. In these areas, the installation of pavement heating systems would improve highway safety. The above five areas of suggested application represent a very small percentage of the pavement area of the total highway system.

The cost of the earth heat pipe pavement heating system is composed of:

- Cost of Heat Pipes
- Cost of Hole Drilling
- Cost of Installation

The delivered cost of each heat pipe manufactured in accordance with the specification in Appendix C and in a nominal length of 50 feet is currently estimated to be 80 dollars. This same pipe, produced in an automated manufacturing facility, is estimated to cost 60 dollars (1973).

The cost of drilling holes (40 feet deep) is currently estimated at 60 dollars/hole in rock and 30 dollars/hole in normal-type soils. These estimates are for quantities of 1000 or more holes at each job site (conventionally available equipment).

The nominal cost of installation, including field bending of the pipes to specification, placing the pipes in the holes and along the pavement forms, and backfilling the holes around the pipes is estimated to be 20 dollars per pipe (1974 construction labor costs).

Summarizing these costs (on a basis of cost per square foot of pavement) for the various climates, assuming a production facility for pipe manufacture, currently available equipment for hole drilling, and a 12-foot wide pavement:

	$\$/Ft^2$ Rock	$\$/Ft^2$ Soil
Mild Climates ($65^{o}F$)	11.70	9.15
Mild Climates ($60^{o}F$)	14.00	11.00
Moderate Climates ($55^{o}F$)	17.50	13.75
Severe Climates ($50^{o}F$)	23.40	18.35
Severe Climates ($45^{o}F$)	35.00	27.50

Projected hole drilling costs using multiple drill rigs designed for this application are estimated to be one-half of those reported above. As experienced at the Fairbank Highway Research Station test site, operating costs for a earth heat pipe system are zero.

VII. CONCLUSIONS AND RECOMMENDATIONS

The heating of pavements to remove snow and deice, although not common, has been utilized throughout the United States. Several companies market electrical heating mats and cables which may be installed in new pavements or on top of existing pavements prior to resurfacing.

This program had as its objectives the quantification of pavement heating technology, the development of a rugged in-pavement heating element (heat pipe), and the development of the technology for using earth heat to heat pavements. The conclusions resulting from this program are:

- The capacity (size) of the energy source required to remove snow and deice a given area of pavement at a specific location is dependent on the method used to operate the heating system. For example, a heating system operating continuously (continuous system) will have a capability of melting about 25% more snow during the first several hours of a heavy snowfall than would be possible under equilibrium melting conditions (Example VI-2). Conversely, a heating system which is turned on when it begins to snow (demand system) will not be capable of melting snow at its equilibrium rate during the first several hours of a heavy snowfall.

- The design capacity of a demand system can be decreased if the snowfall or icing conditions can be anticipated. However, the conditions must be anticipated by several hours in order to make significant reductions in system capacity (Test 2006).

- Heat pipes are rugged in-pavement heating elements. Their performance is sensitive to orientation and noncondensible gases. Orientation sensitivity can be corrected by design and gas generation by improved processing (Appendix A).

- The heat of the earth can be used to melt snow and deice pavements in moderate winter climates (i.e., Baltimore and Washington area). The heat extracted during the Winter (moderate climates) is replenished during the Summer (determined by earth temperature profiles taken over a complete cycle of seasons, Figure II-12).

- Because the earth is a low temperature heat source, heat pipes spaced on 6-inch centers (or greater) in the pavement will result in snow/slush ridges (Figure IV-14) on the pavement surface during a heavy snowfall. It is predicted that traffic will disperse these ridges and result in uniform melting. Without traffic, these snow/slush ridges eventually melt when the snowfall/drifting rate decreases (Figure IV-15).

As in any broad-based research and development program such as that undertaken here, certain questions remain unresolved because of various circumstances. These questions relate to both technology and application and result in the following recommendations.

- The experimental testing was conducted on representative highway pavement test slabs. Traffic effects were not evaluated but are considered to be beneficial to the performance of earth pavement heating systems. Therefore, an earth heated pavement system should be incorporated in a test section of highway (preferably a ramp at a well traveled inter-

change) and its performance, in terms of traffic flow and safety, should be monitored during ice and snow storms.

- The test facility at the Fairbank Highway Research Station has further usefulness. The earth heat pipe test slab should be kept intact and its performance during winter snowfalls should be visually monitored for the next three seasons. The electrical slab should be disassembled and the heat pipes returned to Dynatherm for laboratory testing. Disassembly should be done carefully and the bond interface between the heat pipes and concrete should be evaluated at this time. Of special concern is determining the cause of poor performance of the forked heat pipes.

- The effect of pavement resurfacing should be evaluated. This can be done by resurfacing the earth slab at the test site ($1\frac{1}{2}$" to 2" asphalt) and visually monitoring its snow melting capability during a winter season.

- The thermal resistance between the heat pipe and the ground (Rp-g) was evaluated for the soil conditions at the Fairbank Highway Research Test Station. The thermal resistance used in this report is believed to be representative but this should be confirmed by determining the resistance for other soil conditions.

- Using heat pipes to pump heat down into the earth during the Summer was investigated and technical progress was made (Figure III-10). However, this is a difficult technical problem and the effort was terminated when the program was rescoped to permit additional winter testing within the

originally allotted funds. During the Summer, the pavement is a collector of solar and thermal energy which, if this energy could be stored within the earth, would enhance the snow melting performance of earth pavement heating systems. This work should be reinitiated.

Assuming that the traffic demonstration results in favorable reaction from State highway engineers, incentive would be provided for addressing the application problems. The most significant application problems are those of cost and proper field installation equipment. At the present time, the cost of a heat pipe and the cost of providing the hole in the earth are about equal. Both costs are equipment sensitive and are probably best solved by manufacturers under business incentives.

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APPENDIX A

COMPUTER PROGRAMS

A.1 Nodal Network

The two-dimensional nodal network, which was used throughout this program, was developed using the computer program THERMO. This program is available through the Federal Highway Administration.

This program employs an implicit solution method by inverting the matrix of linearized data using the Gauss elimination method. For steady-state problems, an iterative procedure is used with convergence occurring when all temperature changes are within a specified tolerance. This same iterative procedure is used for transient problem solutions, with each calculation representing a net energy exchange during a specified time interval. In summary, the data input requirements are:

Steady-State Problems:

- Two boundary temperatures in $^{\circ}$F must be specified. The earth source temperature may be taken as the average annual ambient temperature minus the permitted seasonal temperature drop. The boundary temperature for the pavement is taken as the actual ambient temperature for a dry pavement or 33°F for a wet pavement which is undergoing melting.

- Adjacent nodes which transfer heat through conduction must be specified (conductance connections).

- For each conductance connection, the conductances in BTU/Hr-$^{\circ}$F must be specified. These conductances are based on the conductivity of the medium, the interface area between the nodes, and the distance between the nodes.

- The internal dissipation (watts) which are used in simulation of temperature independent heat sources must be specified.

- For dry pavement surfaces, in order to calculate the conductance of the upper surface nodes to the ambient sink, the wind speed in miles per hour must be specified.

Transient Problems (additional input requirements):

- The thermal capacitance in BTU/$^{\circ}$F for each node must be specified. The capacitance is based on the density and specific heat of the medium and on the volume of the selected node.

- The initial temperature of the medium in $^{\circ}F$ must be specified.

Several additional considerations are also necessary. The heat conducted through the ground-concrete interface may be modeled in two ways. If it is assumed that the heat flux passing through this interface is constant, values for internal dissipations can be assigned to the nodes on this interface. However, to obtain a more realistic representation of this heat flux, these nodes can be coupled to the ground source temperature by using experimentally determined conductances. In addition, the modeling of a temperature dependent heat source (earth source) can be accomplished by coupling the heat pipe node to the ground source temperature using specified conductances.

A.2 Averaging Program

The averaging program was developed to read and utilize the data tapes resulting from testing at the Fairbank Highway Research Station. Basically, this program will read the data from tape information covering one data scan. It will group the channel numbers according to their physical location within the test installation, average the groups, and continue this process until the entire tape has been read. In this manner, the program provides the group averages which are used to process the analytical data.

APPENDIX B

GENERAL DATA

Air Temperature (^oF)	Vapor Pressure (inches Hg)	Air Temperature (^oF)	Vapor Pressure (inches Hg)
0	0.038	30	0.164
1	0.040	31	0.172
2	0.042	32	0.180
3	0.044	33	0.187
4	0.047	34	0.195
5	0.049	35	0.203
6	0.052	36	0.211
7	0.054	37	0.219
8	0.057	38	0.228
9	0.060	39	0.237
10	0.063	40	0.247
11	0.067	41	0.256
12	0.070	42	0.266
13	0.074	43	0.277
14	0.077	44	0.287
15	0.081	45	0.298
16	0.085	46	0.310
17	0.089	47	0.322
18	0.093	48	0.334
19	0.098	49	0.347
20	0.103		
21	0.108		
22	0.113		
23	0.118		
24	0.124		
25	0.130		
26	0.136		
27	0.143		
28	0.150		
29	0.157		

TABLE B-1

SATURATION VAPOR PRESSURE AS A FUNCTION OF AIR TEMPERATURE

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: BALTIMORE, MARYLAND FRIENDSHIP INTERNATIONAL AP Standard time used: EASTERN Latitude: 39° 11' N Longitude: 76° 40' W Elevation (ground): 148 feet Year: 1972

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date
JAN	45.4	29.8	37.6	66	13	5	16	841	0	2.62	0.70	4-5	1.1	1.1	27-28
FEB	43.0	25.6	34.3	74	29	11	8	884	0	6.01	1.72	18-19+	11.4	4.0	23
MAR	52.7	34.4	43.6	80	2+	22	11+	663	5	2.38	0.87	16-17	0.2	0.2	5
APR	62.7	40.5	51.6	85	19	28	8+	396	1	5.30	1.54	22	0.3	0.3	7-8
MAY	72.5	52.8	62.7	83	7	40	11	94	29	4.11	1.28	19-20	0.0	0.0	
JUN	77.2	58.9	68.1	89	4	40	11	42	140	9.95	5.23	21-22	0.0	0.0	
JUL	85.3	68.5	76.9	95	23+	56	8+	2	379	2.81	1.32	16	0.0	0.0	
AUG	85.5	65.3	75.4	94	26+	54	11	0	331	2.22	1.02	27	0.0	0.0	
SEP	78.9	60.6	69.8	92	17+	49	23	16	166	1.15	0.40	14	0.0	0.0	
OCT	63.3	43.7	53.5	76	8	28	21+	357	7	3.51	1.92	28	T	T	19
NOV	51.8	34.5	43.2	70	3	20	23	649	0	7.05	1.86	14	T	T	30+
DEC	47.1	33.6	40.4	65	6	14	18	759	0	5.02	1.63	8-9	T	T	16
YEAR	63.8	45.7	54.8	95	JUL. 23+	5	JAN. 16	4703	1058	52.33	5.23	JUN. 21-22	13.0	4.0	FEB. 23

Month	Relative humidity: Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind &: Resultant: Direction	Speed	Average speed	Fastest mile: Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	32° and below	Minimum: 32° and below	0° and below	Average daily solar radiation - langleys
JAN	71	73	62	62	28	3.1	8.2	38	SW	25	52	6.8	8	5	18	16	0	2	7	0	2	19	0	
FEB	66	70	58	59	29	4.6	11.0	38	NW	19+	55	6.2	8	8	13	13	4	0	3	0	4	21	0	
MAR	61	66	50	49	30	3.4	11.1	34	NW	8	55	7.1	4	8	19	7	0	3	0	0	0	15	0	
APR	66	74	53	52	31	2.1	8.9	33	W	20	58	6.3	8	8	14	11	0	4	2	0	0	5	0	
MAY	79	84	59	62	10	1.2	8.6	26	NW	4	53	6.2	7	8	16	12	0	4	2	0	0	0	0	
JUN	83	85	62	67	25	2.7	9.1	37	NW	22	43	7.0	5	9	16	16	0	5	3	0	0	0	0	
JUL	80	82	61	68	25	2.4	7.2	26	NW	16	53	6.2	6	14	11	10	0	6	2	11	0	0	0	
AUG	81	84	53	62	23	2.0	7.2	30	W	7	68	5.2	10	14	7	7	0	5	4	8	0	0	0	
SEP	80	83	61	68	32	1.4	7.8	31	NW	30	49	6.7	8	7	15	9	0	2	2	3	0	0	0	
OCT	75	78	56	62	32	3.2	8.9	32	NW	15	54	5.8	11	5	15	6	0	0	1	0	0	4	0	
NOV	77	80	67	69	30	3.4	8.5	36	W	8	41	6.5	7	9	14	10	0	0	1	0	0	13	0	
DEC	77	80	75	75	31	2.6	9.0	38	W	16	36	8.2	4	5	22	16	0	0	7	0	1	13	0	
YEAR	75	78	60	63	29	2.2	8.8	38	W	DEC. 16+	52	6.5	86	100	180	133	4	31	34	22	7	90	0	

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	22		22		(b)	(b)	22		22		22		22	22		22	
J	44.2	25.3	34.8	75	1967	-7	1963	936	3.43	5.27	1964	0.29	1955	2.54	1968	5.5	21.4	1966	12.1	1966
F	45.5	25.8	35.7	76	1954	-1	1967	820	2.89	6.21	1971	0.72	1968	2.18	1971	6.5	20.1	1967	15.5	1958
M	53.6	32.5	43.1	85	1963	6	1960	679	3.82	6.80	1953	0.93	1966	3.18	1958	5.3	21.6	1960	13.0	1962
A	65.8	42.6	54.2	94	1960	20	1965	327	3.60	8.15	1952	1.61	1968	2.80	1952	0.1	0.4	1964+	0.4	1964+
M	75.9	52.8	64.4	98	1962	32	1966	90	3.98	7.10	1960	0.43	1964	3.64	1960	T	T	1963	T	1963
J	83.5	61.4	72.5	100	1959	40	1972	0	3.29	9.95	1972	0.15	1954	5.23	1972	0.0	0.0		0.0	
J	87.2	66.4	76.8	102	1966+	52	1962+	0	4.22	8.18	1960	0.30	1955	5.86	1952	0.0	0.0		0.0	
A	85.0	65.0	75.0	102	1953	48	1952	0	5.19	18.35	1955	0.77	1951	7.82	1955	0.0	0.0		0.0	
S	78.6	57.6	68.1	99	1962+	35	1963	48	3.33	8.50	1966	0.21	1967	4.33	1960	0.0	0.0		0.0	
O	68.4	45.6	57.0	92	1954+	25	1969+	264	3.18	6.88	1971	T	1963	3.49	1955	T	T	1972+	T	1972+
N	56.5	34.4	45.5	83	1971+	13	1955	585	3.13	7.68	1952	0.68	1965	3.43	1952	1.3	8.4	1967	8.4	1967
D	45.7	25.9	35.8	74	1951	0	1960	905	2.99	7.44	1969	0.20	1955	1.80	1969	4.8	20.4	1966	14.1	1960
YR	65.8	44.6	55.2	102	JUL. 1966+	-7	JAN. 1963	4654	43.05	18.35	AUG. 1955	T	OCT. 1963	7.82	AUG. 1955	23.5	21.6	MAR. 1960	15.5	FEB. 1958

Month	Relative humidity: Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max: 90° and above ‡	32° and below	Min: 32° and below	0° and below	Average daily solar radiation - langleys
(a)	19	19	19	19	22	13	22	22		22	22	22	22	22	22	22	22	22	22	22	22	22	
J	69	72	57	62	10.1	WNW	63	NE	1958	52	6.1	9	7	15	10	2	*	4	0	6	25	*	
F	68	72	56	61	10.8	NW	68	W	1956	54	6.2	8	7	13	9	2	*	4	0	4	22	*	
M	66	71	50	55	11.4	WNW	80	SE	1952	55	6.2	8	9	14	11	2	1	3	0	1	16	0	
A	69	73	49	55	11.1	WNW	70	W	1954	55	6.2	7	10	13	11	*	2	2	*	0	3	0	
M	76	76	51	59	9.7	W	65	SW	1961+	58	6.1	8	11	12	11	0	4	2	2	0	*	0	
J	81	79	52	62	8.9	WNW	80	SW	1952	63	5.7	8	12	10	9	0	6	1	7	0	0	0	
J	81	81	53	64	8.3	W	57	NW	1962	65	5.7	9	12	10	8	0	6	1	11	0	0	0	
A	82	83	55	66	8.4	W	54	NE	1955	63	5.5	10	11	10	10	0	5	1	8	0	0	0	
S	83	84	55	68	8.5	S	56	W	1952	62	5.2	11	9	10	7	0	2	2	4	0	0	0	
O	79	82	53	68	9.2	NW	73	SE	1954	59	5.0	13	7	11	7	0	1	3	*	0	2	0	
N	74	77	54	64	9.6	WNW	58	E	1952	51	6.0	9	8	13	9	*	*	3	0	*	12	0	
D	72	75	59	66	9.6	WNW	57	W	1953	48	6.3	9	7	15	9	1	*	4	0	4	21	*	
YR	75	77	54	62	9.6	W	80	SW	JUN. 1952+	58	5.9	109	110	146	112	8	28	30	32	14	101	*	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locslity as follows: Highest temperature 107 in July 1936; maximum monthly snowfall 33.9 in February 1899; maximum snowfall in 24 hours 24.5 in January 1922.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: BINGHAMTON, NEW YORK BROOME COUNTY AIRPORT Standard time used: EASTERN Latitude: 42° 13' N Longitude: 75° 59' W Elevation (ground): 1590 feet Year: 1971

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Resultant: Direction	Speed	Average speed	Fastest mile: Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	32° and below	Minimum: 32° and below	0° and below	Average daily solar radiation - langleys
JAN	22.3	8.9	15.6	42	5	-9	19	1525	0	1.68	0.48	13-14	17.2	3.6	29-30	80	81	71	70	26	6.8	11.6	56	SW	26	47	7.8	0	11	20	16	7	0	3	0	27	31	9	
FEB	30.0	17.1	23.6	48	27	-7	1	1154	0	4.36	1.60	13	18.7	7.0	7-8	77	82	71	73	23	4.3	10.4	36	SE	5	39	8.3	1	6	21	11	4	0	7	0	14	27	4	
MAR	34.3	22.5	28.4	50	15	13	10	1130	0	2.77	1.36	3-4	33.5	15.8	3-4	72	76	60	67	28	5.7	11.2	42	W	4	43	7.9	2	7	22	16	7	0	5	0	12	30	0	
APR	49.7	31.7	40.7	76	13	21	6	723	0	2.02	1.00	28	0.8	0.4	26	66	70	52	55	30	6.3	11.3	31	NW	18	49	7.0	5	10	15	11	0	0	5	0	0	17	0	
MAY	63.4	45.2	54.3	85	19	34	1	339	13	3.31	1.46	20-21	T	T	3	71	77	58	59	27	2.9	8.6	32	NW	20	54	7.1	5	8	18	11	0	4	4	0	0	0	0	
JUN	76.4	56.1	66.3	86	30+	45	11+	56	101	1.73	0.85	13	0.0	0.0		81	82	58	66	24	2.7	8.6	28	SW	25	76	6.3	4	18	8	7	0	4	1	0	0	0	0	
JUL	75.8	56.0	65.9	86	8	47	18	45	82	4.60	2.16	30-31	0.0	0.0		82	87	61	67	25	3.6	8.8	28	S	13	65	6.0	5	15	11	10	0	8	3	0	0	0	0	
AUG	74.0	54.1	64.1	82	30+	38	24	85	61	2.10	1.06	27-28	0.0	0.0		90	97	64	75	26	3.5	8.8	29	NW	22	63	5.8	8	8	15	8	0	3	4	0	0	0	0	
SEP	70.2	55.3	62.8	85	6	37	25	144	84	1.66	0.48	12	0.0	0.0		95	97	74	85	17	2.8	8.5	23	S	20	38	7.5	2	12	16	11	0	4	10	0	0	0	0	
OCT	63.2	47.5	55.4	79	2	37	13+	296	5	1.89	0.79	9-10	0.0	0.0		85	90	68	72	18	3.5	8.3	32	W	6	40	6.8	6	11	14	8	0	2	9	0	0	0	0	
NOV	42.2	29.3	35.8	74	2	14	24+	872	0	3.17	0.81	24-25	17.9	7.0	24-25	83	86	71	78	25	3.9	10.0	29	W	7	29	8.5	2	5	23	17	7	0	6	0	9	21	0	
DEC	37.9	23.8	30.9	56	15	5	5	1050	0	4.16	1.11	6-7	8.1	1.8	30-1	78	83	72	74	24	4.6	11.3	36	NW	25	26	7.9	3	6	22	19	4	0	8	*	9	24	0	
YEAR	53.3	37.3	45.3	86	JUL. 8+	-9	JAN. 19	7419	346	33.45	2.16	JUL. 30-31	96.2	15.8	MAR. 3-4	80	84	65	70	25	3.5	9.8	56	SW	JAN. 26	50	7.2	43	117	205	145	29	25	65	0	71	150	13	

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max: 90° and above ‡	32° and below	Min: 32° and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	20		20		(b)	(b)	20		20		20		20	20		20		20	20	20	20	20	12	20	20		20	20	20	20	20	20	20	20	20	20	20	20	20	
J	30.1	17.4	23.8	63	1967	-20	1957	1277	2.50	4.31	1958	0.76	1970	1.80	1958	19.9	36.6	1966	18.4	1964	81	81	73	75	11.7	WSW	59	NW	1959	37	8.0	3	6	22	17	6	*	4	0	20	30	4	
F	31.0	16.6	23.8	66	1954	-15	1961	1154	2.18	4.36	1971	0.51	1968	2.16	1966	19.6	39.4	1960	23.0	1961	79	81	70	73	12.0	SSE	66	NW	1956	41	7.9	2	7	19	15	5	*	4	0	16	27	3	
M	39.0	23.6	31.3	72	1968	-6	1967	1045	2.89	5.11	1956	0.69	1969	1.95	1964	16.1	33.5	1971	15.8	1971	78	81	65	70	11.8	NW	61	NW	1955	45	7.7	4	6	21	16	4	1	6	0	10	27	*	
A	52.9	34.1	43.5	84	1962	11	1954	645	2.94	5.09	1964	1.61	1968	1.77	1961	5.0	16.4	1957	11.5	1960	75	78	57	63	11.5	WNW	52	W	1956	50	7.4	5	6	19	14	1	3	5	0	1	12	0	
M	65.3	44.8	55.1	87	1969+	25	1966+	313	3.49	6.46	1968	0.78	1962	1.75	1952	0.3	3.4	1966	3.4	1966	76	79	56	62	10.3	NNW	54	W	1954	58	7.2	4	10	17	13	*	4	4	0	0	2	0	
J	73.4	53.6	63.5	94	1952	36	1958	99	3.85	9.46	1960	1.15	1970	3.11	1960	0.0	0.0		0.0		81	83	58	66	9.2	NNW	60	NW	1957	65	6.7	5	11	14	11	0	7	3	*	0	0	0	
J	78.3	58.5	68.4	95	1966+	39	1963	22	3.71	7.40	1956	0.83	1955	3.01	1952	0.0	0.0		0.0		82	85	58	66	8.5	WSW	58	W	1956	66	6.6	5	13	13	10	0	7	4	1	0	0	0	
A	76.2	56.8	66.5	94	1955	37	1965	65	3.57	7.48	1959	0.61	1953	3.19	1959	0.0	0.0		0.0		84	89	59	69	8.5	SSW	58	N	1958	62	6.5	5	11	15	11	0	5	4	1	0	0	0	
S	68.6	50.3	59.5	96	1953	26	1963	201	2.95	5.57	1960	0.61	1961	3.40	1968	T	T	1970+	T	1970+	86	90	62	73	8.8	SSW	42	NW	1960	59	6.4	6	10	14	9	0	2	5	*	0	*	0	
O	58.7	40.8	49.8	82	1963+	21	1969	471	3.09	9.43	1955	0.26	1963	3.88	1955	0.4	1.9	1952	1.3	1952	80	85	61	70	9.8	WSW	72	S	1954	51	6.7	7	8	16	11	*	1	4	0	*	5	0	
N	44.7	31.3	38.0	74	1971	7	1958	810	2.51	5.62	1968	1.01	1960	2.10	1967	8.0	24.4	1954	10.1	1953	80	83	70	75	11.0	NNW	57	SE	1951	30	8.2	2	6	22	14	2	*	5	0	3	18	0	
D	32.7	20.8	26.8	64	1966	-8	1969	1184	2.56	4.85	1969	0.94	1960	1.51	1952	18.9	59.6	1969	15.6	1969	82	84	75	78	11.4	WSW	59	NW	1956	27	8.4	2	6	23	18	6	*	5	0	17	28	1	
YR	54.2	37.4	45.8	96	SEP. 1953	-20	JAN. 1957	7286	36.24	9.46	JUN. 1960	0.26	OCT. 1963	3.88	OCT. 1955	88.2	59.6	DEC. 1969	23.0	FEB. 1961	80	83	64	70	10.4	WSW	72	S	OCT. 1954	51	7.3	50	100	215	161	25	31	52	3	67	148	8	

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
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* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
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‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

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\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: BOISE, IDAHO MUNICIPAL AIRPORT Standard time used: MOUNTAIN Latitude: 43° 34' N Longitude: 116° 13' W Elevation (ground): 2838 feet Year: 1971

Month	Temperature Averages Daily maximum	Daily minimum	Monthly	Extremes Highest	Date	Lowest	Date	Degree days (Base 65°) Heating	Cooling	Precipitation Total	Greatest in 24 hrs	Date	Snow, Ice pellets Total	Greatest in 24 hrs.	Date
JAN	39.8	28.0	33.9	55	26	6	5+	958	0	2.04	0.75	17-18	4.0	1.9	6-7
FEB	45.6	29.3	37.5	59	12	16	28	765	0	0.65	0.33	18-19	2.1	1.4	28
MAR	49.5	30.8	40.2	66	29	6	1	763	0	1.50	0.41	22-23	1.6	0.8	16 +
APR	60.7	37.7	49.2	73	30	28	19+	465	0	0.40	0.14	23	T	T	10
MAY	72.6	47.3	60.0	86	26	30	18	176	31	0.25	0.12	12-13	0.0	0.0	
JUN	77.1	52.6	64.9	98	22	44	17	78	81	1.58	0.76	25-26	0.0	0.0	
JUL	90.0	59.4	74.7	100	31+	44	7	10	320	0.12	0.12	19	0.0	0.0	
AUG	94.0	63.1	78.6	104	1	44	23	6	435	0.18	0.18	29-30	0.0	0.0	
SEP	72.5	45.8	59.2	93	5	34	16	210	42	0.64	0.25	6	0.0	0.0	
OCT	60.4	37.6	49.0	81	9	11	29	492	2	0.53	0.20	19	2.7	1.7	30-31
NOV	47.8	31.6	39.7	63	9	20	8+	753	0	2.32	0.88	26-27	0.4	0.4	1
DEC	36.7	23.7	30.2	49	24+	11	19	1069	0	1.63	0.47	5	14.8	3.1	12-13
YEAR	62.2	40.6	51.4	104	AUG. 1	6	MAR. 1+	5745	911	11.84	0.88	NOV. 26-27	25.6	3.1	DEC. 12-13

Month	Relative humidity Hour 05 (Local time)	Hour 11	Hour 17	Hour 23	Wind & Resultant Direction	Resultant Speed	Average speed	Fastest mile Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Maximum † 90° and above	Maximum 32° and below	Minimum 32° and below	Minimum 0° and below	Average daily solar radiation - langleys
JAN	77	71	68	76	12	2.9	8.1	29	E	15	41	8.2	4	2	25	17	1	0	7	0	7	19	0	145
FEB	70	59	48	66	34	0.7	9.7	33	W	24	65	7.0	3	10	15	9	1	0	2	0	1	19	0	255
MAR	67	51	45	65	12	2.5	10.8	44	NW	30	65	7.4	5	5	21	12	0	0	0	0	0	19	0	347
APR	64	45	31	53	32	1.4	10.9	33	W	20+	71	6.8	5	9	16	6	0	0	0	0	0	6	0	507
MAY	60	41	29	50	32	1.8	11.0	37	SE	26	70	6.4	6	9	16	8	0	3	0	0	0	1	0	592
JUN	63	42	32	53	33	2.5	9.0	27	SW	12	70	5.4	9	12	9	7	0	2	0	2	0	0	0	637
JUL	54	32	20	41	32	2.2	8.4	34	SW	21	89	2.1	24	4	3	1	0	2	0	20	0	0	0	700
AUG	43	29	19	33	36	0.6	8.3	34	NW	22	84	3.5	15	12	4	2	0	4	0	26	0	0	0	605
SEP	53	39	27	47	19	0.2	9.7	28	W	28	82	3.5	18	6	6	5	0	1	0	2	0	0	0	475
OCT	67	52	40	65	28	0.7	8.8	29	SE	22+	69	5.1	13	6	12	7	2	0	2	0	0	11	0	322
NOV	74	64	54	70	12	2.0	8.6	26	W	26	38	7.5	3	9	18	11	0	0	2	0	0	16	0	164
DEC	74	69	64	73	12	5.3	9.6	34	SE	12+	19	7.9	5	2	24	15	7	0	7	0	8	26	0	128
YEAR	64	50	40	58	08	0.5	9.4	44	NW	MAR. 30	66	5.9	110	86	169	100	11	12	20	50	16	117	0	406

NORMALS, MEANS, AND EXTREMES

Month	Temperature Normal Daily maximum	Normal Daily minimum	Normal Monthly	‡ Extremes Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	32		32		(b)	(b)	32		32		32		32	32		32	
J	36.1	22.1	29.1	63	1953	-17	1950	1113	1.32	3.87	1970	0.12	1949	1.48	1953	7.8	21.4	1964	8.5	1950
F	42.4	26.5	34.5	67	1958	-10	1950	854	1.33	2.17	1945	0.19	1964	1.00	1951	3.9	25.2	1949	13.0	1949
M	51.5	31.9	41.7	78	1966	6	1971	722	1.32	2.27	1957	0.18	1944	1.12	1943	1.9	11.9	1951	6.4	1952
A	63.3	37.4	50.4	92	1946	19	1968	438	1.16	3.04	1955	0.09	1949	1.27	1969	0.8	8.0	1967	7.2	1969
M	71.9	44.5	58.2	98	1966	27	1968+	245	1.29	4.00	1942	0.09	1940	1.51	1942	0.1	4.0	1964	4.0	1964
J	80.5	51.1	65.8	109	1940	33	1962+	81	0.89	3.41	1941	0.01	1966+	2.24	1958	T	T	1954+	T	1954+
J	91.4	59.0	75.2	111	1960	41	1955	0	0.21	0.95	1960	0.00	1947	0.94	1960	T	T	1970	T	1970
A	88.7	55.5	72.1	110	1961	37	1965	0	0.16	2.37	1968	T	1969+	0.79	1960	0.0	0.0		0.0	
S	78.8	46.6	62.7	102	1945	23	1970	132	0.39	2.54	1959	T	1943	0.87	1959	0.0	0.0		0.0	
O	65.3	37.9	51.6	91	1963	11	1971	415	0.84	2.25	1956	T	1952	0.76	1947	0.2	2.7	1971	1.7	1971
N	48.4	28.7	38.6	73	1947	-3	1955	792	1.20	2.41	1963	0.35	1952	0.88	1971	1.5	7.3	1964	6.5	1964
D	39.4	25.0	32.2	65	1964	-1	1949	1017	1.32	3.19	1964	0.25	1962	1.16	1955	5.4	15.6	1951	6.6	1953
YR	63.1	38.9	51.0	111	JUL. 1960	-17	JAN. 1950	5809	11.43	4.00	MAY 1942	0.00	JUL. 1947	2.24	JUN. 1958	21.6	25.2	FEB. 1949	13.0	FEB. 1949

Month	Relative humidity Hour 05 (Local time)	Hour 11	Hour 17	Hour 23	Wind & Mean speed	Prevailing direction #	Fastest mile Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Max † 90° and above	Max 32° and below	Min 32° and below	Min 0° and below	Average daily solar radiation - langleys
(a)	32	32	32	32	32	24	32	32		32	32	32	32	32	32	32	32	32	32	32	32	32	20
J	81	74	72	80	8.7	SE	50	SE	1941	42	7.6	5	5	21	13	3	*	5	0	10	26	2	141
F	81	69	62	78	9.4	SE	56	W	1954	52	7.1	5	6	17	10	2	*	3	0	3	22	*	238
M	74	55	45	68	10.4	SE	52	W	1957	62	6.7	7	7	17	9	1	1	1	0	*	19	0	349
A	71	48	37	61	10.2	SE	50	W	1942	68	6.3	7	9	14	8	*	1	*	*	0	8	0	483
M	70	46	35	60	9.6	NW	50	W	1954+	71	5.8	9	9	13	8	*	3	*	1	0	2	0	589
J	69	43	32	55	9.2	NW	50	SW	1948	75	4.8	12	10	8	7	0	3	*	5	0	0	0	630
J	53	33	22	38	8.5	NW	61	W	1944	89	2.5	22	7	2	2	0	3	0	19	0	0	0	677
A	51	34	23	39	8.3	NW	56	SE	1963	86	3.1	19	8	4	2	0	2	0	15	0	0	0	573
S	59	40	30	49	8.4	SE	50	SE	1960	82	3.6	17	7	6	4	0	2	*	3	0	1	0	460
O	68	49	41	61	8.7	SE	56	SE	1950	68	5.0	12	9	10	7	*	1	1	*	0	6	0	309
N	79	66	62	76	8.7	SE	57	NW	1953	46	6.8	6	7	17	10	1	*	3	0	1	18	*	171
D	82	75	73	81	8.6	SE	56	NW	1950	40	7.6	5	5	21	12	2	*	6	0	6	25	*	122
YR	70	53	44	62	9.1	SE	61	W	JUL. 1944	68	5.6	126	89	150	91	8	15	19	43	19	126	2	395

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Lowest temperature -18 in December 1924; maximum monthly precipitation 7.66 in March 1871; maximum preciptation in 24 hours 2.72 in March 1871; maximum monthly snowfall 36.6 in December 1884; maximum snowfall in 24 hours 17.0 in December 1884.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign. The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: BOSTON, MASSACHUSETTS GEN LOGAN INTERNATIONAL AP Standard time used: EASTERN Latitude: 42° 22' N Longitude: 71° 02' W Elevation (ground): 15 feet Year: 1971

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date	Relative humidity: Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind &: Resultant: Direction	Speed	Average speed	Fastest mile: Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	32° and below	Minimum: 32° and below	0° and below	Average daily solar radiation - langleys
JAN	30.9	16.6	23.8	46	5	2	28+	1269	0	1.88	0.44	1	12.0	4.9	1	66	66	60	58	28	11.1	15.7	36	NW	27	66	5.6	11	10	10	12	5	0	1	0	14	31	0	
FEB	36.8	24.1	30.5	53	13	5	3	962	0	5.05	1.32	8-9	8.1	2.7	5	78	80	66	71	28	4.3	13.9	42	NE	8	55	6.8	7	7	14	11	3	0	3	0	6	26	0	
MAR	43.4	30.0	36.7	65	16	23	25	868	0	3.08	1.40	3-4	7.4	4.0	11	68	68	56	60	29	8.2	15.6	55	SW	4	68	6.5	6	11	14	9	3	0	2	0	0	24	0	
APR	53.6	36.5	45.1	72	13	30	17+	586	0	2.92	1.37	6-7	1.9	1.9	6-7	73	70	58	66	31	4.2	12.7	40	NE	7	60	6.5	6	11	13	14	1	2	2	0	0	9	0	
MAY	63.7	47.6	55.7	79	25+	43	11+	287	6	3.72	1.10	16-17	0.0	0.0		81	78	63	71	26	0.9	10.7	28	SW	25+	47	7.1	5	10	16	12	0	0	2	0	0	0	0	
JUN	79.2	59.0	69.1	94	30	48	2	25	155	1.74	0.56	3	0.0	0.0		70	65	50	58	23	2.8	10.0	29	NE	8+	78	5.0	10	15	5	5	0	5	2	4	0	0	0	
JUL	82.4	64.4	73.4	94	9	58	4	0	269	2.84	0.88	29-30	0.0	0.0		74	69	51	65	23	4.4	10.0	30	W	17+	71	5.8	10	10	11	9	0	4	2	5	0	0	0	
AUG	82.3	64.5	73.4	93	10+	52	24	2	271	1.59	0.83	27-28	0.0	0.0		74	71	51	64	26	3.9	10.3	45	SW	28	76	4.7	12	12	7	7	0	2	3	3	0	0	0	
SEP	75.4	60.5	68.0	92	5	49	25	37	132	1.55	0.94	13-14	0.0	0.0		79	80	64	74	29	0.8	9.4	25	NW	9	59	6.2	6	11	13	7	0	1	4	3	0	0	0	
OCT	67.2	52.4	59.8	86	2	45	8	169	15	2.16	1.43	10-11	0.0	0.0		82	81	63	77	25	0.1	9.9	30	SE	10+	68	5.8	8	13	10	5	0	1	1	0	0	0	0	
NOV	50.0	36.2	43.1	76	1	24	9	651	1	6.74	2.59	25	2.8	1.6	21-22	70	72	58	64	30	4.5	10.7	39	NE	25	43	6.7	9	3	18	13	1	1	1	0	0	8	0	
DEC	43.6	28.9	36.3	64	16+	13	19	882	0	2.40	0.84	30-31	7.9	3.0	30-31	69	72	61	64	29	6.7	12.5	42	NW	25	52	6.0	9	8	14	15	4	0	1	0	3	18	0	
YEAR	59.0	43.4	51.2	94	JUL. 9+	2	JAN. 28+	5738	849	35.67	2.59	NOV. 25	40.1	4.9	JAN. 1	74	73	58	66	28	4.0	11.8	55	SW	MAR. 4	63	6.1	99	121	145	119	17	16	24	15	23	116	0	

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes ∅: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction ##	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90° and above ‡	32° and below	Min.: 32° and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	7		7		(b)	(b)	20		20		20		36	36		36		7	7	7	7	14	15	14	14		36	36	36	36	36	20	36	36	36	7	7	7	7	
J	36.8	23.0	29.9	62	1967	-4	1968+	1088	3.94	9.54	1958	0.89	1970	2.07	1958	12.4	32.5	1948	12.8	1943	66	66	57	61	14.6	NW	52	SW	1960	53	6.2	9	7	15	12	3	*	2	0	12	27	1	
F	37.4	23.1	30.3	58	1970+	-3	1967	972	3.32	7.08	1969	1.15	1968	2.68	1969	12.1	41.3	1969	19.4	1958	67	70	60	63	14.5	WNW	57	S	1970	57	6.1	8	7	13	11	3	*	2	0	8	25	*	
M	44.6	30.7	37.7	66	1966	6	1967	846	4.22	11.00	1953	1.48	1962	4.13	1968	8.4	31.2	1956	17.7	1960	67	69	58	62	14.5	NW	55	SW	1971	58	6.3	8	8	15	12	2	*	2	0	2	19	0	
A	55.7	40.0	47.9	83	1969	22	1965	513	3.77	7.82	1958	1.24	1966	2.09	1954	0.7	3.3	1967	3.1	1956	68	68	55	62	13.7	WNW	52	NW	1963	56	6.4	7	9	14	12	*	1	2	0	0	3	0	
M	67.5	50.1	58.8	93	1964	37	1967	208	3.34	13.38	1954	0.53	1964	5.74	1954	T	T	1967+	T	1967+	72	70	57	63	12.7	SW	50	NE	1967	58	6.5	6	11	14	11	0	2	3	*	0	0	0	
J	76.3	59.2	67.8	95	1969	46	1965	36	3.48	8.63	1959	0.48	1953	2.46	1960	0.0	0.0		0.0		76	72	58	66	11.8	SW	44	NNW	1958	64	6.2	7	11	12	10	0	4	2	3	0	0	0	
J	81.9	65.4	73.7	98	1968	54	1965	0	2.88	8.12	1959	0.52	1952	2.42	1959	0.0	0.0		0.0		76	73	55	65	11.3	SW	45	N	1964	65	6.2	7	12	12	9	0	5	2	4	0	0	0	
A	80.0	63.3	71.7	94	1970	47	1965	9	3.66	17.09	1955	1.25	1966	8.40	1955	0.0	0.0		0.0		77	74	56	66	11.3	SW	65	NNW	1958	66	5.6	10	10	11	10	0	4	2	2	0	0	0	
S	73.4	57.1	65.3	95	1969	38	1965	60	3.46	8.31	1954	0.35	1957	5.64	1954	0.0	0.0		0.0		80	79	61	72	11.5	SW	57	S	1960	64	5.4	11	8	11	9	0	2	2	1	0	0	0	
O	62.7	47.2	55.0	86	1971	30	1969	316	3.14	8.68	1962	0.96	1967	4.26	1962	T	T	1970+	T	1970+	76	77	58	68	12.3	SW	45	NW	1963	61	5.5	11	8	12	9	0	1	2	0	0	1	0	
N	51.9	37.8	44.9	76	1971	21	1967	603	3.93	8.18	1969	1.72	1952	3.33	1955	1.3	10.0	1938	8.0	1940	74	76	64	70	13.2	SW	58	SW	1958	51	6.4	8	7	15	12	*	*	2	0	*	7	0	
D	40.1	26.5	33.3	70	1966	-3	1968	983	3.63	9.74	1969	1.03	1955	4.17	1969	8.1	27.9	1970	13.0	1960	69	71	61	65	14.1	WNW	49	NW	1962	54	6.2	9	8	14	11	2	*	1	0	6	21	*	
YR	59.0	43.6	51.4	98	JUL. 1968	-4	JAN. 1968+	5634	42.77	17.09	AUG. 1955	0.35	SEP. 1957	8.40	AUG. 1955	43.0	41.3	FEB. 1969	19.4	FEB. 1958	72	72	58	65	13.0	SW	65	NNW	AUG. 1958	60	6.1	101	106	158	127	11	19	23	10	29	103	1	

∅ For period April 1964 through current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 104 in July 1911; lowest temperature -18 in February 1934; minimum monthly precipitation T in March 1915; fastest mile wind 87 S in September 1938.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\## Data for the year 1958 are fastest observed 1-minute speeds with directions to 16 compass points; otherwise data are fastest mile with directions to 8 compass points.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: CHICAGO, ILLINOIS MIDWAY AIRPORT Standard time used: CENTRAL Latitude 41° 47' N Longitude 87° 45' W Elevation (ground): 607 feet Year: 1971

Month	Temperature – Averages – Daily maximum	Temperature – Averages – Daily minimum	Temperature – Averages – Monthly	Temperature – Extremes – Highest	Date	Temperature – Extremes – Lowest	Date	Degree days (Base 65°) – Heating	Degree days – Cooling	Precipitation – Total	Precipitation – Greatest in 24 hrs.	Date	Snow, Ice pellets – Total	Snow, Ice pellets – Greatest in 24 hrs.	Date	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18
JAN	27.0	11.4	19.2	44	25	-4	31+	1413	0	1.11	0.82	3-4	12.8	7.1	3	63	66	60	60
FEB	35.5	20.9	28.2	59	26+	-9	2	1023	0	2.39	0.87	26	5.0	3.2	12-13	72	72	65	68
MAR	43.5	27.8	35.7	74	31	17	9+	903	0	3.30	1.28	18-19	14.8	4.5	18	70	72	61	60
APR	59.8	37.6	48.7	86	12	23	3	482	2	0.45	0.16	27	0.8	0.8	2-3	60	66	46	47
MAY	68.8	46.3	57.6	89	17	32	3	257	29	1.98	1.05	5-6	T	T	2	63	69	45	45
JUN	87.1	64.5	75.8	101	28+	49	9	10	341	2.18	0.54	1-2	0.0	0.0		68	72	51	54
JUL	82.1	63.2	72.7	94	4	53	31+	5	246	5.00	1.88	23	0.0	0.0		71	74	53	50
AUG	82.0	62.8	72.4	96	20	54	17	2	237	1.96	1.00	24	0.0	0.0		77	84	57	59
SEP	79.4	61.3	70.4	95	8	44	24	56	226	3.47	1.91	5-6	0.0	0.0		75	81	60	61
OCT	71.8	52.5	62.2	92	1	37	31	146	64	0.85	0.27	8	0.0	0.0		76	81	60	64
NOV	50.3	33.7	42.0	78	14	18	7	683	0	0.96	0.43	28-29	1.2	0.7	8-9	72	77	62	64
DEC	43.9	29.4	36.7	64	15	13	18	871	0	5.93	2.19	9-10	0.3	0.3	17	78	79	71	74
YEAR	60.9	42.6	51.8	101	JUN. 28+	-9	FEB. 2	5851	1145	29.58	2.19	DEC. 9-10	34.9	7.1	JAN. 3	70	74	58	59

Month	Wind & – Resultant – Direction	Resultant – Speed	Average speed	Fastest mile – Speed	Fastest mile – Direction #	Fastest mile – Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	Maximum – 32° and below	Minimum – 32° and below	Minimum – 0° and below	Average daily solar radiation - langleys
JAN	25	6.8	13.4	39	W	29	55	6.0	11	5	15	8	3	0	0	0	18	31	7	
FEB	24	5.7	13.5	42	SW	27	30	7.5	5	2	21	14	2	1	1	0	10	23	3	
MAR	29	3.5	12.8	33	SW	15	49	7.0	7	5	19	12	6	4	1	0	4	26	0	
APR	34	1.0	12.4	33	N	23	68	4.9	12	11	7	8	0	3	0	0	0	8	0	
MAY	22	0.6	10.9	32	N	11	67	5.5	9	12	10	8	0	6	0	0	0	1	0	
JUN	19	1.7	9.7	34	NE	18	73	5.3	10	11	9	11	0	10	0	13	0	0	0	
JUL	23	2.6	9.6	28	SW	13	62	5.6	8	14	9	12	0	9	1	4	0	0	0	
AUG	20	0.6	9.5	39	N	22	73	4.6	12	13	6	6	0	4	0	8	0	0	0	
SEP	17	3.5	9.6	29	SW	5	59	6.1	6	15	9	9	0	4	0	8	0	0	0	
OCT	21	3.5	9.2	38	S	27	71	5.7	9	13	9	7	0	2	2	2	0	0	0	
NOV	23	4.8	12.2	43	S	1	55	6.4	8	8	14	8	0	2	0	0	1	13	0	
DEC	22	3.8	10.6	42	S	15	34	7.9	5	6	20	14	0	1	3	0	1	18	0	
YEAR	23	2.7	11.1	43	S	NOV. 1	60	6.0	102	115	148	117	11	46	8	35	34	120	10	

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Normal – Daily minimum	Normal – Monthly	Extremes Ø – Record highest	Year	Extremes – Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs	Year	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	8		8		(b)	(b)	29		29		29		29	29		29	
J	33.0	19.0	26.0	65	1967	-16	1966	1209	1.86	4.09	1965	0.26	1961	2.86	1960	9.7	28.9	1967	19.8	1967
F	34.7	20.6	27.7	59	1971+	-9	1971+	1044	1.60	3.35	1950	0.25	1969	1.54	1960	7.9	22.5	1967	8.3	1956
M	43.5	29.0	36.3	78	1968+	8	1965	890	2.74	5.00	1954	0.33	1958	2.50	1948	7.7	22.3	1965	14.3	1970
A	57.4	40.5	49.0	88	1970	23	1971	480	3.04	8.33	1947	0.45	1971	4.08	1947	1.1	10.7	1970	10.7	1970
M	69.1	50.9	60.0	93	1967	29	1966	211	3.73	7.59	1945	0.78	1950	3.63	1966	T	0.2	1966+	0.2	1966+
J	79.5	61.5	70.5	101	1971	43	1969	48	4.07	8.89	1950	0.78	1956	4.58	1959	0.0	0.0		0.0	
J	84.1	67.1	75.6	99	1970	50	1967+	0	3.37	8.98	1957	1.33	1945	6.24	1957	0.0	0.0		0.0	
A	82.4	65.9	74.2	98	1964	43	1965	0	3.16	6.79	1965	0.85	1962	3.83	1968	0.0	0.0		0.0	
S	74.8	57.4	66.1	95	1971	38	1970	81	2.73	14.17	1961	0.46	1956	2.63	1961	0.0	0.0		0.0	
O	63.4	46.7	55.1	94	1963	27	1964	326	2.78	12.06	1954	0.20	1964	5.63	1954	0.3	4.4	1967	4.4	1967
N	47.1	32.6	39.9	78	1971	7	1964	753	2.20	5.05	1966	0.89	1949	2.93	1966	2.5	14.3	1951	8.0	1951
D	35.7	22.5	29.1	71	1970	-10	1967	1113	1.90	6.67	1949	0.30	1962	2.79	1965	9.7	33.3	1951	12.5	1960
YR	58.7	42.8	50.8	101	JUN. 1971	-16	JAN. 1966	6155	33.18	14.17	SEP. 1961	0.20	OCT. 1964	6.24	JUL. 1957	38.9	33.3	DEC. 1951	19.8	JAN. 1967

Month	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind & – Mean speed	Prevailing direction	Fastest mile – Speed	Fastest mile – Direction #	Fastest mile – Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max – 90° and above ‡	Max – 32° and below	Min – 32° and below	Min – 0° and below	Average daily solar radiation - langleys
(a)	8	8	8	8	29	19	29	29		29	29	29	29	29	29	29	29	29	8	8	8	8	
J	69	70	64	66	11.5	W	50	W	1950	44	7.0	6	7	18	10	3	*	2	0	17	28	5	
F	68	70	60	64	11.7	W	51	SW	1967	47	6.8	7	5	16	10	2	*	2	0	11	26	2	
M	68	73	58	60	11.9	W	54	NW	1955	51	7.0	6	8	17	12	2	2	1	0	4	22	0	
A	67	72	55	56	11.8	W	50	NW	1951	53	6.7	6	9	15	13	*	4	1	0	0	4	0	
M	67	71	51	51	10.5	SSW	54	S	1950	61	6.2	8	9	14	12	0	5	1	1	0	*	0	
J	68	74	54	54	9.3	SW	50	W	1953	67	6.0	7	11	12	11	0	7	*	7	0	0	0	
J	72	77	55	56	8.3	SW	46	NW	1959	69	5.3	10	12	9	9	0	6	*	7	0	0	0	
A	74	79	55	57	8.1	SW	54	NW	1949	68	5.2	11	11	9	8	0	5	1	4	0	0	0	
S	75	80	55	59	9.0	S	48	SW	1959	64	5.3	10	10	10	9	0	4	*	2	0	0	0	
O	69	77	53	58	9.8	S	45	S	1949	62	5.3	11	9	11	8	*	2	1	*	0	2	0	
N	73	77	63	68	11.4	SSW	60	SW	1952	41	7.0	6	7	17	10	1	1	1	0	2	14	0	
D	75	78	70	72	11.2	W	50	SW	1948	40	7.1	6	7	18	11	3	*	2	0	10	24	*	
YR	70	75	58	60	10.4	W	60	SW	NOV. 1952	57	6.2	94	105	166	120	12	38	13	21	44	119	7	

Ø For period August 1963 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 105 in July 1934; lowest temperature -23 in December 1872; minimum monthly precipitation 0.06 in February 1877; maximum monthly snowfall 42.5 in January 1918; fastest mile of wind 87 from Northeast in February 1894.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: GREATER CINCINNATI AIRPORT BOONE COUNTY, KENTUCKY Standard time used: EASTERN Latitude: 39° 04' N Longitude: 84° 40' W Elevation (ground): 869 feet Year: 1971

Month	Temperature – Averages – Daily maximum	Temperature – Averages – Daily minimum	Temperature – Averages – Monthly	Temperature – Extremes – Highest	Temperature – Extremes – Date	Temperature – Extremes – Lowest	Temperature – Extremes – Date	Degree days (Base 65°) – Heating	Degree days (Base 65°) – Cooling	Precipitation – Total	Precipitation – Greatest in 24 hrs.	Precipitation – Date	Snow, Ice pellets – Total	Snow, Ice pellets – Greatest in 24 hrs	Snow, Ice pellets – Date	Relative humidity – Hour 01 (Local time)	Relative humidity – Hour 07	Relative humidity – Hour 13	Relative humidity – Hour 19
JAN	37.3	19.3	28.3	58	14	2	31	1133	0	2.47	1.12	13-14+	3.2	1.3	30	70	72	62	64
FEB	42.2	24.4	33.3	69	22	-3	2	881	0	5.89	2.23	21-22	13.3	6.4	8	69	73	64	66
MAR	50.0	30.4	40.2	74	14	17	4	758	0	2.55	0.64	10	9.7	3.1	19-20+	74	81	60	60
APR	66.6	39.5	53.1	82	12	30	10+	351	0	1.04	0.56	1	T	T	2 +	63	71	42	45
MAY	72.7	48.9	60.8	86	17	30	4	157	33	3.31	1.18	7	0.0	0.0		72	75	49	52
JUN	86.3	65.3	75.8	97	27	54	10	0	335	5.18	1.45	19	0.0	0.0		77	79	55	58
JUL	84.4	65.1	74.8	92	9	55	28	0	313	3.70	1.10	28	0.0	0.0		78	80	55	59
AUG	83.0	61.8	72.4	90	18	54	24+	0	236	3.45	1.58	3-4	0.0	0.0		84	89	57	64
SEP	78.5	62.0	70.3	89	1	45	21	31	195	6.56	1.59	20	0.0	0.0		85	90	67	77
OCT	71.7	51.0	61.4	84	2+	37	12+	128	25	1.44	0.54	23-24	0.0	0.0		82	87	60	71
NOV	52.2	34.1	43.2	74	14	14	8	649	0	1.68	0.45	29	3.0	1.6	6	74	76	61	67
DEC	49.3	33.0	41.2	67	10	12	18	731	0	3.39	0.99	30	T	T	31 +	77	78	68	71
YEAR	64.5	44.6	54.6	97	JUN. 27	-3	FEB. 2	4819	1137	40.66	2.23	FEB. 21-22	29.2	6.4	FEB. 8	75	79	56	63

Month	Wind & – Resultant – Direction	Wind & – Resultant – Speed	Wind & – Average speed	Wind & – Fastest mile – Speed	Wind & – Fastest mile – Direction	Wind & – Fastest mile – Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Number of days – Partly cloudy	Number of days – Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	Temperatures – Maximum – 32° and below	Temperatures – Minimum – 32° and below	Temperatures – Minimum – 0° and below	Average daily solar radiation - langleys
JAN	26	5.3	11.0	40	27	26		7.2	5	10	16	7	2	2	3	0	13	29	0	
FEB	23	5.2	12.2	35	28	27+		7.8	3	7	18	15	5	0	2	0	8	19	4	
MAR	26	4.8	12.6	33	24	19+		7.7	5	4	22	12	3	1	2	0	0	16	0	
APR	30	2.1	10.7	29	25	9		5.3	10	10	10	4	0	2	2	0	0	4	0	
MAY	26	2.7	9.2	26	19	24		6.7	6	12	13	9	0	2	1	0	0	1	0	
JUN	21	2.6	7.3	40	24	7		6.3	5	13	12	12	0	7	2	6	0	0	0	
JUL	23	2.7	7.9	26	33	10		6.5	4	14	13	12	0	7	1	5	0	0	0	
AUG	24	0.1	6.6	20	29	22+		5.7	9	12	10	7	0	5	5	1	0	0	0	
SEP	14	1.3	6.9	29	30	20		7.0	3	11	16	12	0	6	11	0	0	0	0	
OCT	18	1.6	6.8	23	16	27		5.5	12	5	14	7	0	1	8	0	0	0	0	
NOV	23	4.0	9.6	26	29	21		6.9	8	3	19	9	1	0	1	0	1	18	0	
DEC	22	3.6	10.3	37	22	15		6.2	2	7	22	12	0	0	8	0	1	15	0	
YEAR	24	2.6	9.3	40	24	JUN. 7+		6.7	72	108	185	118	11	33	46	14	23	102	4	

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Temperature – Normal – Daily minimum	Temperature – Normal – Monthly	Temperature – Extremes – Record highest	Temperature – Extremes – Year	Temperature – Extremes – Record lowest	Temperature – Extremes – Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Precipitation – Maximum monthly	Precipitation – Year	Precipitation – Minimum monthly	Precipitation – Year	Precipitation – Maximum in 24 hrs.	Precipitation – Year	Snow, Ice pellets – Mean total	Snow, Ice pellets – Maximum monthly	Snow, Ice pellets – Year	Snow, Ice pellets – Maximum in 24 hrs.	Snow, Ice pellets – Year
(a)	(b)	(b)	(b)	10		10		(b)	(b)	24		24		24		24	24		24	
J	40.5	22.7	31.6	69	1967	-19	1963	1035	3.56	9.43	1950	0.75	1967	4.33	1959	6.6	15.3	1964	7.6	1964
F	42.6	23.5	33.1	69	[illegible]	-10	1965+	893	2.91	6.72	1955	0.61	1958	2.32	1950	5.2	13.3	1971+	9.3	1966
M	50.9	30.2	40.6	79	[illegible]	9	1970	756	3.79	12.18	1964	1.14	1960	5.21	1964	5.2	13.0	1968	9.8	1968
A	63.6	40.8	52.2	87	1962	17	1964	390	3.22	7.19	1970	1.04	1971	2.72	1950	0.3	3.3	1953	3.3	1953
M	74.2	50.7	62.5	93	1962	27	1963	149	3.59	9.48	1968	1.13	1964	3.71	1956	T	T	1966+	T	1966+
J	83.5	60.1	71.8	97	1971	41	1966	24	3.89	6.16	1960	0.95	1965	3.25	1959	0.0	0.0		0.0	
J	87.4	63.3	75.4	100	1970	47	1963	0	3.61	8.36	1962	1.18	1951	3.47	1953	0.0	0.0		0.0	
A	86.1	62.0	74.1	102	1962	43	1965	0	2.60	6.10	1954	0.31	1953	3.12	1957	0.0	0.0		0.0	
S	79.6	54.8	67.2	98	1964	33	1963+	75	2.83	8.25	1950	0.18	1963	3.30	1950	0.0	0.0		0.0	
O	68.1	44.0	56.1	88	1963	16	1962	291	2.26	4.49	1955	0.25	1963	2.13	1955	0.1	1.7	1962	1.7	1962
N	52.5	32.8	42.7	79	1968	6	1964	669	3.01	6.25	1957	0.43	1949	3.36	1946	2.6	12.1	1966	9.0	1966
D	42.0	24.6	33.3	70	1970+	-11	1963	983	2.75	6.17	1951	0.58	1955	2.96	1948	4.0	12.5	1960	6.0	1951
YR	64.3	42.5	53.4	102	AUG. 1962	-19	JAN. 1963	5265	38.02	12.18	MAR. 1964	0.18	SEP. 1963	5.21	MAR. 1964	24.0	15.3	JAN. 1964	9.8	MAR. 1966

Month	Relative humidity – Hour 01 (Local time)	Relative humidity – Hour 07	Relative humidity – Hour 13	Relative humidity – Hour 19	Wind & – Mean speed	Wind & – Prevailing direction	Wind & – Fastest mile – Speed	Wind & – Fastest mile – Direction	Wind & – Fastest mile – Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Mean number of days – Partly cloudy	Mean number of days – Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max – 90° and above ‡	Temperatures – Max – 32° and below	Temperatures – Min. – 32° and below	Temperatures – Min. – 0° and below	Average daily solar radiation - langleys
(a)	9	9	9	9	24	16	6	8			20	20	20	20	24	24	24	8	9	9	9	9	
J	73	76	64	67	10.8	SSW	40	27	1971		7.5	5	7	19	12	2	1	2	0	12	26	3	
F	74	78	62	64	10.7	SSW	40	29	1967		7.3	5	6	17	11	2	1	2	0	7	24	2	
M	72	77	59	61	11.2	SSW	37	23	1964		7.4	5	7	19	13	2	2	2	0	2	17	0	
A	70	76	53	54	11.0	SSW	40	25	1970		7.1	5	8	17	13	*	4	1	0	0	4	0	
M	75	77	52	55	9.0	SSW	35	24	1965+		6.7	6	10	15	12	0	6	1	1	0	*	0	
J	78	79	53	56	7.8	SSW	40	24	1971+		6.2	7	11	12	10	0	7	1	7	0	0	0	
J	82	84	55	59	7.1	SSW	35	32	1966		6.1	7	12	12	10	0	9	2	8	0	0	0	
A	81	86	54	60	6.7	SSW	29	30	1964		5.6	8	13	10	8	0	8	2	6	0	0	0	
S	81	86	56	65	7.5	SSW	29	30	1971+		5.5	10	9	11	8	0	3	4	3	0	0	0	
O	75	82	52	62	6.1	SSW	35	27	1967		5.4	12	7	12	8	*	1	3	0	0	3	0	
N	73	78	61	67	9.7	SSW	35	20	1968+		7.0	6	6	18	11	1	1	2	0	1	14	0	
D	76	78	68	71	10.2	SSW	37	22	1971		7.5	5	6	20	12	1	*	3	0	7	22	1	
YR	76	60	57	62	9.1	SSW	40	24	JUN. 1971+		6.6	81	102	182	127	7	44	24	24	29	110	6	

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
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‡ ≥ 70° at Alaskan stations.

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Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: CONCORD, NEW HAMPSHIRE MUNICIPAL AIRPORT   Standard time used: EASTERN   Latitude 43° 12' N   Longitude 71° 30' W   Elevation (ground): 342 feet   Year: 1971

Month	Temperature – Averages – Daily maximum	Daily minimum	Monthly	Extremes – Highest	Date	Lowest	Date	Degree days (Base 65°) – Heating	Cooling	Precipitation – Total	Greatest in 24 hrs	Date	Snow, Ice pellets – Total	Greatest in 24 hrs.	Date
JAN	25.3	-.3	12.5	43	25	-29	19	1622	0	1.63	0.51	26	15.6	4.2	30
FEB	34.0	12.5	23.3	49	28+	-27	3	1165	0	3.87	0.96	13	19.8	5.6	8
MAR	39.4	21.4	30.4	56	16	5	13	1064	0	2.28	0.84	3-4	24.0	7.6	19-20
APR	54.3	29.8	42.1	74	13	17	9	682	0	2.19	0.54	7	6.3	5.6	7
MAY	67.5	40.6	54.1	83	12	28	15	332	0	3.36	1.13	2-3	0.0	0.0	
JUN	80.8	50.1	65.5	95	30	32	6	73	95	1.67	0.53	8	0.0	0.0	
JUL	83.0	53.6	68.3	92	9	40	13+	26	135	5.14	2.54	29-30	0.0	0.0	
AUG	79.9	54.0	67.0	89	9	36	25	49	118	2.79	1.03	27-28	0.0	0.0	
SEP	72.7	49.5	61.1	88	4	27	25	165	55	1.91	1.10	12	0.0	0.0	
OCT	65.2	38.6	51.9	84	2	26	13	396	0	2.69	1.76	10-11	0.0	0.0	
NOV	42.7	22.1	32.4	72	1	6	24	970	0	2.91	0.93	29-30	18.4	9.4	25-26
DEC	36.7	16.4	26.6	54	16+	-8	19	1185	0	2.36	0.53	30-31	17.4	7.5	30-31
YEAR	56.8	32.4	44.6	95	JUN. 30	-29	JAN. 19	7729	403	32.80	2.54	JUL. 29-30	101.5	9.4	NOV. 25-26

Month	Relative humidity – Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & – Resultant – Direction	Speed	Average speed	Fastest mile – Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	32° and below	Minimum – 32° and below	0° and below	Average daily solar radiation - langleys
JAN	72	73	60	64	29	5.5	8.9	35	NW	3	66	5.1	13	8	10	9	4	0	2	0	21	31	16	
FEB	75	75	60	66	30	1.8	8.0	29	NW	19	58	7.1	4	10	14	11	5	0	4	0	12	28	6	
MAR	67	68	52	56	31	7.0	10.8	35	W	5	68	5.8	10	10	11	8	5	0	2	0	5	30	0	
APR	73	75	47	55	32	5.3	9.7	35	NW	7	59	6.9	5	9	16	14	1	1	3	0	0	20	0	
MAY	85	80	50	58	28	1.5	8.2	26	W	14	52	6.7	7	5	19	12	0	0	0	0	0	5	0	
JUN	86	79	41	55	24	2.2	7.4	38	W	8	73	4.9	9	18	3	5	0	3	0	2	0	1	0	
JUL	93	87	47	60	25	2.5	7.1	45	SW	1	71	5.9	6	15	10	9	0	6	2	3	0	0	0	
AUG	92	91	52	68	27	2.8	7.4	30	SE	28+	69	5.3	11	11	9	9	0	4	4	0	0	0	0	
SEP	94	96	61	81	27	0.2	5.5	29	W	17	50	6.7	5	9	16	7	0	2	10	0	0	1	0	
OCT	92	92	58	83	19	0.6	5.7	25	W	12	51	6.6	6	11	14	6	0	1	10	0	0	8	0	
NOV	84	86	61	71	31	4.5	7.6	30	W	30+	48	6.9	6	7	17	11	5	0	4	0	3	26	0	
DEC	70	74	60	65	31	4.9	8.1	39	NW	25	50	6.2	8	8	15	16	6	0	4	0	9	30	5	
YEAR	82	81	54	65	30	2.9	7.9	45	SW	JUL. 1	61	6.2	90	121	154	117	26	17	45	5	50	180	27	

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Daily minimum	Monthly	Extremes Ø – Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	6		6		(b)	(b)	30		30		30		30	30		30	
J	31.7	10.6	21.2	59	1966	-29	1971	1358	3.23	5.83	1958	0.40	1970	1.66	1964	16.9	33.2	1945	19.0	1944
F	33.5	11.8	22.7	57	1966	-27	1971	1184	2.48	5.54	1951	0.93	1968	2.10	1951	15.8	49.8	1969	13.8	1969
M	41.7	21.7	31.7	68	1968	-16	1967	1032	3.26	7.81	1953	0.93	1965	1.93	1968	11.5	38.3	1956	13.6	1959
A	55.9	31.7	43.8	88	1969	8	1969	636	3.31	5.10	1951	1.16	1966	2.10	1945	1.9	9.9	1956	6.8	1956
M	69.3	41.6	55.5	93	1970	21	1966	298	3.17	8.26	1954	0.60	1965+	2.19	1954	0.2	5.0	1945	5.0	1945
J	77.7	51.3	64.5	97	1966	31	1967	75	3.60	10.10	1944	0.81	1964	4.47	1944	0.0	0.0		0.0	
J	82.8	56.4	69.6	102	1966	35	1965	6	3.41	5.91	1967	0.96	1955+	2.54	1971	0.0	0.0		0.0	
A	80.6	54.1	67.4	96	1970+	29	1965	50	2.96	5.90	1959	0.95	1944+	3.56	1954	0.0	0.0		0.0	
S	72.4	46.2	59.3	92	1970	22	1965	177	3.75	7.78	1960	0.41	1948	4.12	1960	0.0	0.0		0.0	
O	61.7	35.6	48.7	84	1971+	10	1969	505	2.66	8.78	1962	0.59	1947	4.24	1962	0.1	2.1	1969	2.1	1969
N	47.9	27.2	37.6	72	1971	-1	1967	822	3.72	6.78	1963	1.27	1946	2.89	1947	4.0	18.4	1971	9.5	1961
D	35.1	14.8	25.0	61	1970+	-17	1969	1240	3.25	7.10	1969	0.58	1943	3.31	1969	13.7	38.1	1956	14.6	1946
YR	57.5	33.6	45.6	102	JUL. 1966	-29	JAN. 1971	7383	38.80	10.10	JUN. 1944	0.40	JAN. 1970	4.47	JUN. 1944	64.1	49.8	FEB. 1969	19.0	JAN. 1944

Month	Relative humidity – Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & – Mean speed	Prevailing direction #	Fastest mile – Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max – 90° and above ‡	32° and below	Min – 32° and below	0° and below	Average daily solar radiation - langleys
(a)	6	6	6	6	30	22	29	29		30	30	30	30	30	30	30	30	30	6	6	6	6	
J	71	70	57	64	7.3	NW	43	NW	1945	51	6.1	9	8	14	11	4	*	2	0	17	31	11	
F	73	75	60	64	7.9	NW	42	N	1950	54	6.1	8	7	13	10	5	*	2	0	13	27	8	
M	74	77	56	62	8.2	NW	71	NE	1950	52	6.2	8	8	15	11	3	*	3	0	4	26	1	
A	75	77	46	54	7.8	NW	52	NW	1945	52	6.4	7	9	14	11	1	1	2	0	0	19	0	
M	81	77	46	56	7.1	NW	48	NW	1945	54	6.6	7	9	15	12	*	3	3	*	0	7	0	
J	90	86	54	67	6.3	NW	38	W	1971+	58	6.1	7	12	11	10	0	5	*	2	0	*	0	
J	92	87	53	66	5.6	NW	45	SW	1971	62	6.0	7	13	11	10	0	6	6	5	0	0	0	
A	91	89	53	70	5.3	NW	56	E	1934	60	5.7	9	12	10	10	0	4	8	2	0	0	0	
S	93	93	59	80	5.4	NW	42	E	1960+	55	5.8	10	8	12	9	0	2	9	*	0	2	0	
O	86	88	55	75	5.9	NW	39	NW	1944	54	5.7	10	9	12	8	*	1	7	0	*	11	0	
N	83	84	63	75	6.6	NW	72	NE	1950	41	6.8	6	8	16	12	1	*	4	0	2	21	*	
D	77	79	64	70	7.1	NW	52	NW	1962	48	6.2	8	9	14	11	4	*	3	0	15	28	5	
YR	82	82	55	67	6.7	NW	72	NE	NOV. 1950	54	6.1	96	112	157	124	18	21	52	9	51	171	26	

Ø For period April 1965 through current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Lowest temperature -37 in February 1943; maximum monthly precipitation 10.97 in September 1888; minimum monthly precipitation T in March 1915; maximum precipitation in 24 hours 5.97 in September 1932; maximum monthly snowfall 59.0 in February 1893.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: GRAND RAPIDS, MICHIGAN KENT COUNTY AIRPORT Standard time used: EASTERN Latitude: 42° 53' N Longitude: 85° 31' W Elevation (ground): 784 feet Year: 1971

Month	Temperature Averages Daily maximum	Daily minimum	Monthly	Extremes Highest	Date	Lowest	Date	Degree days (Base 65°) Heating	Cooling	Precipitation Total	Greatest in 24 hrs.	Date	Snow, Ice pellets Total	Greatest in 24 hrs.	Date	Relative humidity Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & Resultant Direction	Resultant Speed	Average speed	Fastest mile Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Maximum 90° and above ‡	Maximum 32° and below	Minimum 32° and below	Minimum 0° and below	Average daily solar radiation - langleys
JAN	25.4	11.1	18.3	41	4	-9	19	1441	0	1.04	0.27	29-30	27.2	6.0	5-6	77	80	70	74	24	7.2	13.8	56	W	29	33	8.8	0	7	24	17	8	0	1	0	24	31	6	
FEB	30.6	17.6	24.1	51	26	-11	2+	1140	0	2.48	0.95	18-19	4.4	1.1	9-10	77	77	72	72	23	5.8	14.1	58	SW	5	27	8.6	2	2	24	16	0	1	6	0	13	24	3	
MAR	36.8	21.2	29.0	64	31+	0	25	1110	0	1.77	0.65	6-7	25.9	8.0	18-19	73	77	63	66	28	3.1	11.7	44	SW	15	42	8.0	3	7	21	9	6	1	2	0	9	29	1	
APR	55.7	32.0	43.9	77	12	13	4	626	0	2.27	1.42	12-13	4.1	3.3	2-3	69	73	50	50	28	3.3	10.8	36	SW	2	61	5.8	9	8	13	11	1	4	1	0	1	15	0	
MAY	67.6	40.4	54.0	81	17	26	4+	342	8	1.05	0.39	24-25	0.0	0.0		73	78	43	45	24	3.0	10.5	42	W	24	69	5.8	8	13	10	7	0	2	0	0	0	4	0	
JUN	82.8	59.0	70.9	96	28	40	10	35	218	2.01	0.75	20	0.0	0.0		79	62	55	54	22	3.3	8.4	41	W	6	73	5.7	7	13	10	9	0	6	1	6	0	0	0	
JUL	80.7	57.7	69.2	89	7+	46	31	15	154	2.46	0.92	4-5	0.0	0.0		80	81	51	50	24	4.4	9.6	35	W	13	71	5.7	7	15	9	8	0	3	1	0	0	0	0	
AUG	82.2	54.9	68.6	90	22+	45	24	11	129	0.92	0.65	10	0.0	0.0		78	84	45	51	23	3.0	8.8	38	SW	10	76	4.5	13	11	7	6	0	2	1	3	0	0	0	
SEP	75.3	55.8	65.6	90	8+	35	24	107	132	6.30	1.68	5-6	0.0	0.0		82	84	61	69	17	2.4	8.4	25	NW	23	48	7.4	3	11	16	12	0	6	1	2	0	0	0	
OCT	67.9	48.6	58.3	87	2+	33	12	233	31	1.39	0.54	13	0.0	0.0		85	87	64	75	17	3.1	8.7	30	SW	31	46	6.8	5	12	14	6	0	1	7	0	0	0	0	
NOV	46.0	30.0	38.0	68	17	14	23	800	0	2.84	0.84	19-20	14.9	3.8	26-27	81	81	65	72	22	3.7	11.3	43	SW	6	30	8.2	2	6	22	16	5	0	1	0	4	20	0	
DEC	38.3	25.7	32.0	62	10	12	1	1016	0	6.63	2.13	10	3.7	1.6	29-30	81	81	76	79	22	3.6	11.0	60	SW	10	15	8.7	2	4	25	15	1	2	7	0	5	24	0	
YEAR	57.4	37.8	47.6	96	JUN. 28	-11	FEB. 2+	6878	672	31.16	2.13	DEC. 10	80.2	8.0	MAR. 18-19	78	80	60	63	23	3.4	10.6	60	SW	DEC. 10	53	7.0	61	109	195	132	21	28	29	11	56	147	10	

NORMALS, MEANS, AND EXTREMES

Month	Temperature Normal Daily maximum	Normal Daily minimum	Normal Monthly	Extremes Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & Mean speed	Prevailing direction	Fastest mile Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Max 90° and above ‡	Max 32° and below	Min. 32° and below	Min. 0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	8		8		(b)	(b)	8		8		8		8	8		8		8	8	8	8	8		8	8		8	8	8	8	8	8	8	8	8	8	8	8	8	
J	31.3	16.7	24.0	62	1967	-16	1966	1271	1.91	3.99	1965	1.04	1971	1.28	1965	23.5	29.8	1967	12.6	1967	80	82	73	77	11.5		56	W	1971	35	8.1	3	5	23	16	7	*	4	0	19	30	5	
F	32.2	16.4	24.3	54	1966	-16	1967	1139	1.75	2.48	1971	0.33	1969	1.33	1968	11.0	17.5	1967	7.5	1966	78	78	67	72	11.5		58	SW	1971	42	7.4	4	6	18	12	4	*	2	0	14	27	2	
M	41.5	23.9	32.7	75	1967	-5	1967	1001	2.28	3.54	1964	1.08	1968	1.51	1965	15.6	36.0	1965	13.2	1970	76	80	63	67	11.3		44	SW	1971+	48	7.4	4	8	19	12	4	2	2	0	7	26	1	
A	56.6	34.8	45.7	88	1970	10	1965	579	2.94	5.28	1964	2.27	1971	1.79	1970	2.9	7.8	1970	7.8	1970	76	80	59	60	11.4		54	N	1967	52	6.7	7	7	16	12	1	4	2	0	*	13	0	
M	68.9	44.9	56.8	89	1965	22	1966	323	3.46	4.24	1970	1.05	1971	1.97	1964	T	T	1967+	T	1967+	75	78	52	54	10.6		50	SW	1964	61	6.2	7	11	13	10	0	4	1	0	0	3	0	
J	79.4	55.6	67.5	96	1971	37	1969+	71	3.31	8.21	1967	2.01	1971	3.21	1970	0.0	0.0		0.0		79	79	55	57	9.1		58	W	1964	64	6.0	7	11	12	11	0	7	1	3	0	0	0	
J	84.5	60.0	72.3	97	1966	43	1968	8	2.73	6.42	1969	1.95	1966	2.53	1969	0.0	0.0		0.0		79	80	54	56	8.6		44	W	1970	65	5.6	9	11	11	9	0	7	2	5	0	0	0	
A	82.6	58.2	70.4	100	1964	41	1964	27	2.70	5.36	1965	0.14	1969	1.59	1966	0.0	0.0		0.0		81	85	53	58	8.6		48	SW	1968	67	5.0	12	11	8	8	0	4	2	3	0	0	0	
S	74.3	50.0	62.2	90	1971	32	1965+	135	2.98	7.18	1970	0.93	1969	1.68	1971	T	T	1967+	T	1967+	84	87	59	70	8.8		54	SW	1964	53	6.6	6	10	14	11	0	5	2	*	0	*	0	
O	62.7	39.5	51.1	87	1971	19	1969	435	2.61	6.30	1969	0.60	1964	2.01	1969	1.1	8.4	1967	8.4	1967	82	85	62	72	9.9		54	SW	1969	47	6.7	6	10	15	10	*	2	3	0	0	6	0	
N	46.2	28.4	37.3	73	1964	5	1969	831	2.49	7.81	1966	2.13	1964	2.66	1966	10.3	16.6	1966	8.3	1965	83	85	71	78	10.7		50	SW	1965	27	8.3	2	6	22	14	3	2	3	0	3	18	0	
D	34.3	19.7	27.0	65	1970	-11	1967	1178	2.03	6.63	1971	0.66	1969	2.13	1971	15.7	33.3	1970	15.1	1970	82	83	76	81	10.7		80	SW	1971	26	8.5	2	5	24	16	6	1	4	0	14	27	1	
YR	57.9	37.4	47.6	100	AUG. 1964	-16	FEB. 1967+	6998	31.19	8.21	JUN. 1967	0.14	AUG. 1969	3.21	JUN. 1970	80.1	36.0	MAR. 1965	15.1	DEC. 1970	79	82	62	67	10.2		60	SW	DEC. 1971	51	6.9	69	101	195	141	25	36	28	11	57	149	9	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 108 in July 1936; lowest temperature -24 in February 1899; maximum monthly precipitation 13.22 in June 1892; minimum monthly precipitation 0.02 inFebruary 1877; maximum precipitation in 24 hours 4.58 in June 1905; maximum monthly snowfall 54.0 at Weather Bureau Office (Post Office Building) in December 1951; fastest mile of wind 80 from Southwest in November 1940. See the 1964 issue of this publication for a complete tabulation of data from the earlier location of Kent County Airport.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: GREEN BAY, WISCONSIN AUSTIN STRAUBEL FIELD Standard time used: CENTRAL Latitude: 44° 29' N Longitude: 88° 08' W Elevation (ground): 682 feet Year: 1971

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Temperature: Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date	Relative humidity: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind: Resultant: Direction	Resultant: Speed	Average speed	Fastest mile: Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	Maximum: 32° and below	Minimum: 32° and below	Minimum: 0° and below	Average daily solar radiation - langleys
JAN	16.8	-3.0	6.9	33	1	-21	8	1797	0	1.60	0.75	3-4	20.8	8.6	3-4	78	81	72	75	28	6.3	12.0	33	NW	26	51	5.8	13	4	14	11	5	1	0	0	30	31	21	
FEB	24.3	6.0	15.2	40	26+	-26	2	1391	0	2.03	0.81	19	11.0	5.2	22-23	78	81	73	74	26	2.6	12.0	50	SW	27	43	6.8	6	7	15	13	3	0	3	0	20	28	10	
MAR	34.3	17.4	25.9	46	31	-1	4	1206	0	2.04	0.87	14-15	14.8	7.7	18-19	77	80	66	68	29	3.2	10.3	31	NE	19	51	6.6	7	9	15	11	4	1	5	0	14	29	2	
APR	55.1	32.2	43.7	75	20	15	3	636	0	1.05	0.71	27-28	0.2	0.2	2	71	75	51	57	29	1.8	10.9	33	SW	11	62	5.4	10	10	10	5	0	1	0	0	2	14	0	
MAY	66.2	39.8	53.0	83	15	30	3	365	1	1.67	1.04	18-19	T	T	11	73	79	51	53	29	0.9	10.3	38	SW	19	58	5.8	11	8	12	7	0	1	1	0	0	2	0	
JUN	81.8	57.8	69.8	97	28+	42	9	43	195	1.87	0.65	22	0.0	0.0		81	81	57	61	19	2.1	8.7	31	SW	18+	63	6.0	9	7	14	8	0	8	2	5	0	0	0	
JUL	79.8	55.7	67.8	91	16+	45	31	32	125	3.44	0.79	8	0.0	0.0		80	84	51	58	26	3.7	10.0	29	SW	12	62	6.0	6	14	11	14	0	7	1	2	0	0	0	
AUG	77.3	53.2	65.3	89	9	45	4	57	71	2.99	1.27	22	0.0	0.0		81	83	58	61	28	1.8	8.2	30	SW	1	67	5.3	11	11	9	8	0	6	3	0	0	0	0	
SEP	72.7	51.8	62.3	87	4+	35	24	155	77	3.36	1.35	27	0.0	0.0		83	86	62	68	21	2.1	8.7	30	SW	28	46	6.4	8	10	12	11	0	5	3	0	0	0	0	
OCT†	62.9	46.3	54.6	84	2+	30	12	328	15	2.01	0.62	19-20	0.0	0.0		84	88	74	77	21	1.9	9.6	43	† SW	30	32	7.7	3	7	21	11	0	1	3	0	0	3	0	
NOV	42.2	27.2	34.7	66	17	11	30	902	0	3.21	1.07	1-2	12.6	6.5	26	85	86	71	77	27	3.3	10.9	33	SW	5	28	7.7	2	12	16	15	3	1	0	0	5	22	0	
DEC	31.0	15.9	23.5	42	10	-3	1	1282	0	3.15	1.17	14-15	13.2	6.7	30	82	82	76	81	26	3.7	9.8	34	NE	30	30	7.9	3	8	20	12	2	0	7	0	14	30	2	
YEAR	53.7	33.4	43.6	97	JUN. 28+	-26	FEB. 2	8194	484	28.42	1.35	SEP. 27	72.6	8.6	JAN. 3-4	79	82	64	68	26	2.4	10.1	50	SW	FEB. 27	52	6.5	89	107	169	126	17	32	28	7	85	159	35	

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

In Col. 17 of the October issue, also correct to NE and SW on the 29th and 30th respectively.

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind: Mean speed	Prevailing direction #	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90° and above ‡	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	11		11		(b)	(b)	22		22		22		22	22		22		10	10	10	10	22	14	22	22		22	22	22	22	22	22	22	22	22	10	10	10	10	
J	25.1	8.5	16.8	48	1964	-27	1963	1494	1.15	2.64	1950	0.31	1961	1.05	1950	9.7	20.8	1971	8.6	1971	77	77	72	74	11.0	SW	61	W	1950	45	6.6	8	6	17	10	3	*	2	0	25	31	13	
F	26.9	9.3	18.1	54	1964	-26	1971	1313	1.08	3.56	1953	0.04	1969	1.78	1966	7.7	20.6	1962	9.2	1959	75	77	68	69	10.9	SW	66	W	1951	51	6.2	8	6	14	8	3	*	3	0	21	28	9	
M	36.0	20.4	28.2	73	1967	-29	1962	1141	1.34	2.66	1951	0.46	1957	0.97	1960	8.6	19.6	1959	10.1	1964	77	80	65	67	10.9	NE	68	W	1951	53	6.4	8	8	15	11	3	1	3	0	9	28	1	
A	52.4	33.9	43.2	87	1962	14	1964	654	2.46	5.52	1953	0.98	1963	1.75	1953	1.7	6.9	1957	3.9	1963	76	80	58	60	11.6	NE	59	SW	1964	50	6.6	7	8	15	10	1	3	3	0	*	14	0	
M	65.3	44.2	54.8	88	1970	21	1966	335	3.06	7.75	1960	0.89	1951	2.73	1956	0.2	2.6	1960	2.2	1960	77	79	56	59	10.8	NE	54	SW	1968	56	6.3	7	10	14	12	*	5	1	0	0	3	0	
J	75.4	55.5	65.5	97	1971	35	1966+	99	3.36	8.47	1967	1.05	1964	2.65	1969	0.0	0.0		0.0		81	83	59	61	9.3	SW	73	SW	1953+	62	5.9	8	11	11	11	0	8	2	2	0	0	0	
J	82.0	59.0	70.5	97	1966	40	1965	28	2.71	6.50	1950	1.87	1960	2.95	1959	0.0	0.0		0.0		83	86	57	59	8.3	SW	70	NE	1957	64	5.5	9	12	10	10	0	7	1	3	0	0	0	
A	80.0	57.8	68.9	96	1965	38	1967+	50	2.75	5.50	1951	0.90	1955	2.62	1951	0.0	0.0		0.0		84	88	58	62	8.0	SW	50	SW	1950	63	5.4	10	11	10	9	0	5	3	1	0	0	0	
S	71.3	49.6	60.5	88	1970	28	1966	174	2.92	7.80	1965	0.46	1967	2.99	1964	T	T	1965	T	1965	86	89	62	70	9.2	SW	66	W	1951	55	5.8	9	10	11	10	0	4	2	0	0	1	0	
O	59.6	39.1	49.4	88	1963	15	1966	484	1.91	5.00	1954	T	1952	3.68	1954	0.1	1.7	1959	1.6	1959	81	86	63	70	10.1	SW	65	SW	1951	49	6.2	8	9	14	9	*	2	3	0	0	7	0	
N	41.2	27.1	34.2	70	1964	5	1964	924	1.91	3.52	1957	0.39	1953	1.25	1957	3.9	12.6	1971	6.5	1971	81	83	70	76	11.4	SW	67	W	1955	36	7.3	5	7	18	9	1	1	3	0	4	22	0	
D	29.1	14.8	22.0	62	1970	-19	1967+	1333	1.18	3.15	1971	0.10	1960	1.55	1959	9.0	26.7	1968	7.2	1961	81	81	72	77	10.8	SW	52	W	1957+	37	7.1	6	7	18	10	3	*	3	0	20	29	7	
YR	53.7	34.9	44.3	97	JUN. 1971+	-29	MAR. 1962	8029	25.83	8.47	JUN. 1967	T	OCT. 1952	3.68	OCT. 1954	40.9	26.7	DEC. 1968	10.1	MAR. 1964	80	82	63	67	10.2	SW	73	SW	JUN. 1953+	53	6.3	93	105	167	118	13	36	28	6	79	162	30	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 104 in July 1936; lowest temperature -36 in January 1888; maximum monthly precipitation 9.70 in May 1918; maximum precipitation in 24 hours 4.41 in June 1914; maximum monthly snowfall 32.1 in March 1923; maximum snowfall in 24 hours 22.0 in January 1889.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: INDIANAPOLIS, INDIANA   WEIR COOK MUNICIPAL AIRPORT   Standard time used: EASTERN   Latitude: 39° 44' N   Longitude: 86° 17' W   Elevation (ground): 792 feet   Year: 1971

Month	Temperature – Averages – Daily maximum	Daily minimum	Monthly	Extremes – Highest	Date	Lowest	Date	Degree days (Base 65°) – Heating	Cooling	Precipitation – Total	Greatest in 24 hrs.	Date	Snow, Ice pellets – Total	Greatest in 24 hrs.	Date
JAN	32.3	14.5	23.4	54	4	-3	27	1281	0	1.98	1.60	3-4	1.5	1.1	28
FEB	36.6	21.1	28.9	56	26	-5	2	1006	0	5.35	1.68	4	8.2	5.9	12
MAR	46.9	27.7	37.3	73	31	17	8+	852	0	1.49	0.54	6-7	2.8	1.1	19-20
APR	64.6	37.4	51.0	82	20	26	7	417	2	1.16	0.44	1	T	T	6 +
MAY	70.9	46.8	58.9	84	18+	31	3	198	17	4.25	1.61	11-12	0.0	0.0	
JUN	85.1	66.0	75.6	94	27	55	10	0	324	3.39	2.08	11-12	0.0	0.0	
JUL	82.2	62.3	72.3	91	8	50	31	3	237	5.68	1.73	23-24	0.0	0.0	
AUG	82.0	60.5	71.3	89	10	50	12	1	202	1.93	0.72	14	0.0	0.0	
SEP	79.1	59.6	69.4	89	30+	41	21	49	189	3.10	1.40	19-20	0.0	0.0	
OCT	73.0	50.9	62.0	88	1	34	12	129	40	1.84	0.85	21-22	0.0	0.0	
NOV	52.8	33.4	43.1	76	14	16	7	648	0	1.29	0.33	28-29	4.4	1.8	23-24
DEC	46.4	30.4	38.4	66	10	12	18	813	0	6.02	2.21	14-15	0.4	0.4	19
YEAR	62.7	42.6	52.7	94	JUN. 27	-5	FEB. 2	5397	1011	37.48	2.21	DEC. 14-15	17.3	5.9	FEB. 12

Month	Relative humidity – Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind & – Resultant – Direction	Speed	Average speed	Fastest mile – Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	32° and below	Minimum – 32° and below	0° and below	Average daily solar radiation - langleys
JAN	76	78	64	66	26	4.7	10.4	42	W	26	54	7.0	7	5	19	9	1	0	3	0	14	31	2	173
FEB	81	82	75	78	23	4.0	12.5	38	SW	27	45	7.5	3	8	17	14	1	0	2	0	11	24	3	199
MAR	73	79	58	60	27	4.0	12.3	39	SW	15	50	6.9	7	6	18	11	1	1	2	0	4	26	0	
APR	59	68	44	43	30	1.3	10.3	32	W	28	76	5.1	12	9	9	4	0	1	0	0	0	7	0	454
MAY	73	74	49	51	26	2.0	9.3	38	W	16	67	6.0	8	10	13	9	0	6	0	0	0	2	0	504
JUN	77	79	60	61	20	3.1	8.1	55	W	11	76	5.4	11	10	9	11	0	10	0	5	0	0	0	578
JUL	80	84	59	60	25	2.3	7.8	30	NW	8	70	6.0	8	13	10	12	0	11	0	2	0	0	0	523
AUG	82	87	58	62	31	1.0	7.3	29	SW	23	75	5.4	14	7	10	6	0	5	0	0	0	0	0	493
SEP	85	90	64	70	15	0.9	8.4	27	N	11	58	6.5	6	11	13	10	0	3	2	0	0	0	0	349
OCT	85	90	57	67	19	2.0	7.6	27	SW	27	60	5.1	12	9	10	7	0	2	4	0	0	0	0	297
NOV	77	82	61	69	23	3.7	10.3	38	SW	2	41	6.9	7	6	17	11	3	0	1	0	0	14	0	186
DEC	83	85	71	79	20	2.8	10.5	56	SW	10	19	8.2	3	6	22	14	0	0	5	0	0	22	0	107
YEAR	78	82	60	64	24	2.2	9.6	56	SW	DEC. 10	60	6.3	98	100	167	118	6	39	19	7	29	126	5	

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Daily minimum	Monthly	Extremes – Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	13		13		(b)	(b)	32		32		29	
J	37.1	21.0	29.1	70	1967	-18	1963	1113	3.05	12.69	1950	0.21	1944	3.47	1950
F	39.4	22.8	31.1	67	1962	-10	1965	949	2.28	5.35	1971	0.37	1947	2.32	1950
M	48.1	29.7	38.9	80	1967+	-6	1960	809	3.41	10.74	1963	1.03	1941	3.05	1963
A	61.2	40.3	50.8	89	1970	20	1961	432	3.74	8.09	1964	1.07	1946	2.56	1961
M	72.0	50.7	61.4	93	1965	28	1966	177	3.99	10.10	1943	1.42	1964	3.53	1961
J	81.8	60.4	71.1	96	1962	42	1969	39	4.62	9.74	1942	1.07	1967	3.80	1963
J	86.0	64.3	75.2	99	1970+	48	1968	0	3.50	8.11	1958	0.99	1941	4.00	1969
A	84.7	62.7	73.7	97	1964+	41	1965	0	3.03	6.64	1949	0.68	1964	2.72	1949
S	78.0	54.9	66.5	96	1964	34	1970	90	3.24	6.01	1955	0.24	1963	3.07	1961
O	66.8	44.0	55.4	88	1971	20	1962	316	2.62	8.36	1941	0.17	1963	3.90	1959
N	50.0	31.8	40.9	78	1961	4	1959	723	3.09	5.52	1950	0.89	1949	3.02	1955
D	39.0	23.2	31.1	70	1970	-14	1963	1051	2.68	6.70	1957	0.47	1958	2.21	1971
YR	62.0	42.2	52.1	99	JUL. 1970+	-18	JAN. 1963	5699	39.25	12.69	JAN. 1950	0.17	OCT. 1963	4.00	JUL. 1969

Month	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity – Hour 01	Hour 07	Hour 13	Hour 19 (Local time)	Wind & – Mean speed	Prevailing direction	Fastest mile ∅ – Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max – 90° and above ‡	32° and below	Min – 32° and below	0° and below	Average daily solar radiation - langleys
(a)	40	40		29		12	12	12	12	23	14	27	27		29	29	40	40	40	32	30	29	29	12	12	12	12	19
J	4.9	17.0	1968	10.3	1965	77	79	68	70	11.1	NW	90	W	1950	41	7.2	6	6	19	11	2	1	4	0	14	27	5	162
F	5.1	15.3	1965	12.5	1965	76	78	65	68	11.1	WNW	65	SW	1948	51	6.8	6	6	16	10	2	1	2	0	9	26	2	234
M	3.8	10.1	1959	5.6	1948	74	79	62	64	11.8	WNW	68	NW	1947	52	7.0	6	7	18	12	1	3	2	0	4	19	*	315
A	0.4	4.0	1940	3.1	1953	71	77	55	56	11.5	SW	60	W	1956	56	6.9	6	8	16	12	*	5	1	0	0	5	0	410
M	T	T	1966+	T	1966+	77	81	57	58	9.7	SW	68	W	1951+	62	6.5	7	9	15	12	0	7	1	1	0	1	0	536
J	0.0	0.0		0.0		78	82	57	58	8.4	SW	77	N	1946	68	6.1	7	11	12	10	0	7	1	5	0	0	0	556
J	0.0	0.0		0.0		83	87	60	62	7.4	SW	57	W	1957+	70	5.8	9	12	10	9	0	8	1	6	0	0	0	542
A	0.0	0.0		0.0		84	89	59	63	7.1	SW	54	NW	1946	72	5.3	10	12	9	8	0	6	2	3	0	0	0	497
S	0.0	0.0		0.0		83	89	58	63	8.1	SW	61	NW	1952	68	5.3	11	9	10	8	0	3	1	2	0	0	0	400
O	T	1.2	1962	1.2	1962	79	86	56	62	8.9	SW	56	NW	1952	65	5.1	12	8	11	7	*	2	1	0	0	4	0	296
N	2.1	8.3	1966	8.2	1966	79	85	66	71	10.8	SW	59	SW	1948	43	6.8	7	7	16	10	1	1	2	0	1	15	0	175
D	4.2	12.9	1969	5.6	1948	79	82	71	75	10.6	SW	56	SW	1971	40	7.2	5	7	19	11	2	*	3	0	10	25	2	134
YR	20.5	17.0	JAN. 1968	12.5	FEB. 1965	78	83	61	64	9.7	SW	90	W	JAN. 1950	59	6.3	92	102	171	121	7	44	20	16	37	122	8	355

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 107 in July 1934; lowest temperature -25 in January 1884; maximum monthly precipitation 13.12 in July 1875; minimum monthly precipitation 0.07 in March 1910; maximum precipitation in 24 hours 6.80 in September 1895; maximim monthly snowfall 30.4 in March 1906; fastest mile of wind 111 from Northwest in June 1929.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≤ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

∅ Beginning with 1943 but omitting 1962 and 1963.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: KNOXVILLE, TENNESSEE MC GHEE TYSON AIRPORT Standard time used: EASTERN Latitude: 35° 49' N Longitude: 83° 59' W Elevation (ground): 980 feet Year 1971

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date
JAN	47.5	29.5	38.5	65	13	14	31	813	0	5.03	1.62	24	1.3	0.9	31
FEB	50.5	28.3	39.4	71	22	3	10	710	0	4.93	1.25	21-22	6.4	4.4	13
MAR	55.7	35.4	45.6	78	14	21	9	596	0	4.21	1.02	28-29	3.6	1.8	3-4
APR	71.4	45.5	58.5	85	19	34	7+	209	20	3.87	1.50	6-7	7.0	7.0	6-7
MAY	74.1	53.7	63.9	84	24+	35	4	76	50	3.78	1.78	12-13	0.0	0.0	
JUN	85.9	65.8	75.9	93	26	54	1	0	333	3.73	1.00	28-29	0.0	0.0	
JUL	83.1	67.7	75.4	92	10	62	21	0	328	8.76	2.73	18-19	0.0	0.0	
AUG	85.3	66.7	76.0	89	20+	59	26	0	350	3.05	1.19	3	0.0	0.0	
SEP	81.6	64.9	73.3	90	10+	55	14	0	252	3.41	1.21	20	0.0	0.0	
OCT	74.7	55.8	65.3	85	4+	40	11	53	69	1.98	0.83	4-5	0.0	0.0	
NOV	57.7	39.6	48.7	77	2	26	8	496	13	2.21	0.86	2-3	T	T	26 +
DEC	58.4	42.3	50.4	73	15+	22	18	450	3	5.48	1.23	3	T	T	3
YEAR	68.8	49.6	59.2	93	JUN. 26	3	FEB. 10	3403	1418	50.44	2.73	JUL. 18-19	18.3	7.0	APR. 6-7

Month	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Resultant: Direction	Speed	Average speed	Fastest mile: Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	32° and below	Minimum: 32° and below	0° and below	Average daily solar radiation - langleys
JAN	73	76	61	64	30	3.9	8.8	33	SW	30	40	7.5	5	5	21	13	0	0	6	0	3	21	0	
FEB	73	80	59	58	26	3.5	7.9	34	SW	22	52	6.8	4	9	15	13	2	2	2	0	6	14	0	
MAR	64	72	51	51	27	4.3	9.3	35	W	19	57	6.3	8	9	14	16	2	3	4	0	0	13	0	
APR	60	71	37	38	26	2.4	7.9	30	W	21	77	4.7	12	8	10	9	2	5	0	0	0	0	0	
MAY	71	78	51	53	27	2.2	7.7	30	SW	25	56	6.2	7	10	14	11	0	6	1	0	0	0	0	
JUN	86	89	60	66	28	1.8	6.1	34	NW	29	59	6.6	4	10	16	14	0	15	6	6	0	0	0	
JUL	90	92	70	72	25	2.6	6.5	26	N	14+	44	7.6	4	9	18	16	0	9	1	3	0	0	0	
AUG	90	93	61	68	01	1.6	5.7	20	SW	3	59	5.8	8	13	10	10	0	6	12	0	0	0	0	
SEP	87	91	65	73	02	1.4	5.4	22	N	12	43	6.8	6	9	15	9	0	4	8	2	0	0	0	
OCT	88	92	64	73	03	2.0	5.5	20	E	20	48	6.0	8	10	13	9	0	4	11	0	0	0	0	
NOV	77	78	56	63	33	2.4	7.0	25	W	29	48	5.6	12	6	12	9	0	1	3	0	0	7	0	
DEC	78	81	68	73	31	1.9	8.2	34	SW	15	17	7.9	4	4	23	14	0	0	5	0	0	4	0	
YEAR	78	83	59	63	29	1.9	7.2	35	W	MAR. 19	51	6.5	82	102	181	143	6	55	59	11	9	59	0	

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	11		11		(b)	(b)	30		30		30	
J	50.1	32.6	41.4	72	1967	-9	1966	732	4.88	11.74	1954	1.63	1955	3.89	1946
F	52.7	33.4	43.1	74	1962	0	1970	613	4.81	9.38	1944	0.74	1968	2.89	1956
M	59.9	39.2	49.6	86	1963	18	1969+	493	4.73	9.92	1963	2.26	1957	4.82	1963
A	69.9	47.8	58.9	89	1965	27	1964	198	3.70	7.20	1970	0.84	1942	2.32	1957
M	78.9	56.4	67.7	94	1962	34	1963	43	3.50	6.40	1946	0.74	1970	2.35	1953
J	86.4	64.9	75.7	96	1964	44	1966	0	3.33	7.58	1969	0.20	1944	2.73	1967
J	88.5	68.2	78.4	98	1966	51	1961	0	4.82	10.09	1967	0.70	1957	4.69	1942
A	87.5	67.2	77.4	99	1968	53	1968+	0	3.46	8.88	1942	0.77	1954	3.25	1959
S	83.8	60.6	72.2	96	1962	36	1967	30	2.54	8.61	1944	0.50	1961	5.08	1944
O	73.0	48.8	60.9	85	1971	25	1962	171	2.61	6.67	1949	T	1963	2.44	1961
N	59.2	38.1	48.7	83	1961	13	1970	489	3.24	10.36	1948	0.97	1942	4.06	1948
D	50.3	32.8	41.6	75	1970	-2	1962	725	4.23	11.63	1961	0.45	1965	4.89	1969
YR	70.0	49.2	59.6	99	AUG. 1968	-9	JAN. 1966	3494	45.85	11.74	JAN. 1954	T	OCT. 1963	5.08	SEP. 1944

Month	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90° and above ‡	32° and below	Min.: 32° and below	0° and below	Average daily solar radiation - langleys
(a)	29	30		30		11	11	11	11	29	14	29	29		29	29	29	29	29	29	29	29	29	11	11	11	11	
J	4.0	15.1	1962	12.0	1962	76	79	63	65	8.2	NE	60	SW	1959	38	7.1	6	7	18	13	1	1	3	0	3	21	1	
F	3.8	23.3	1960	17.5	1960	72	77	60	59	8.7	NE	61	SW	1958	45	6.7	7	5	16	12	1	1	2	0	1	17	*	
M	1.8	20.2	1960	12.1	1942	69	77	53	54	9.3	NE	61	SW	1947	52	6.6	8	7	16	12	1	3	1	0	*	10	0	
A	0.2	7.0	1971	7.0	1971	70	78	51	51	9.3	WSW	71	SW	1944	58	6.1	8	9	13	11	*	5	1	0	0	1	0	
M	T	T	1945	T	1945	78	83	53	55	7.4	SW	59	SW	1952	61	6.0	8	11	12	11	0	6	2	2	0	0	0	
J	0.0	0.0		0.0		85	88	59	62	6.7	SW	65	W	1948	61	5.9	7	13	10	11	0	9	2	4	0	0	0	
J	0.0	0.0		0.0		86	90	62	65	6.4	WSW	73	SW	1961	59	6.1	6	13	12	12	0	10	2	7	0	0	0	
A	0.0	0.0		0.0		87	91	60	66	5.7	NE	56	S	1962	59	5.6	8	13	10	10	0	7	3	5	0	0	0	
S	0.0	0.0		0.0		85	90	57	65	5.9	NE	56	W	1943	59	5.5	10	10	10	8	0	3	4	2	0	0	0	
O	T	T	1962	T	1962	82	87	54	61	5.9	NE	42	SW	1947	60	4.8	13	8	10	8	0	1	5	0	0	1	0	
N	1.1	18.2	1952	18.2	1952	78	83	59	65	7.2	NE	43	SW	1960	47	6.1	9	7	14	10	*	1	3	0	*	8	0	
D	2.2	12.2	1963	8.9	1969	76	80	63	67	7.6	NE	52	SW	1954+	36	6.9	7	6	18	11	1	*	3	0	2	17	*	
YR	13.1	23.3	FEB. 1960	18.2	NOV. 1952	79	84	58	61	7.4	NE	73	SW	JUL. 1961	56	6.1	97	109	159	127	4	48	31	21	7	76	1	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 104 in July 1930; lowest temperature -16 in January 1884; maximum monthly precipitation 17.32 in April 1874; maximum precipitation in 24 hours 6.30 in July 1917; maximum monthly snowfall 25.7 in February 1895.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ $\geq$ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: LEXINGTON, KENTUCKY BLUE GRASS FIELD Standard time used: EASTERN Latitude: 38° 02' N Longitude: 84° 36' W Elevation (ground): 966 feet Year: 1971

Month	Temperature – Averages – Daily maximum	Daily minimum	Monthly	Extremes – Highest	Date	Lowest	Date	Degree days (Base 65°) – Heating	Cooling	Precipitation – Total	Greatest in 24 hrs.	Date	Snow, Ice pellets – Total	Greatest in 24 hrs.	Date	Relative humidity – Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & – Resultant – Direction	Speed	Average speed	Fastest mile – Speed	Direction	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	32° and below	Minimum – 32° and below	0° and below	Average daily solar radiation - langleys
JAN	38.3	21.0	29.7	60	14	5	31	1087	0	3.29	1.43	13-14	4.0	2.5	30	76	79	64	70	25	4.2	10.0	30	28	26		7.2	5	9	17	9	2	2	4	0	13	27	0	
FEB	44.4	25.2	34.8	69	18	-2	2+	838	0	4.72	0.94	21-22	9.1	7.3	8	72	76	61	66	21	5.1	11.6	25	29	27		7.3	5	5	18	12	2	1	2	0	6	17	3	
MAR	50.7	29.9	40.3	73	14	17	24	759	0	2.02	0.68	6	5.3	2.7	3-4	69	74	54	56	24	5.0	12.6	32	27	15		6.7	4	14	13	9	1	2	2	0	1	21	0	
APR	65.2	38.8	52.0	80	13	28	7	382	0	2.10	0.82	1	0.0	0.0		64	68	43	50	26	1.4	9.8	29	21	1		4.7	12	11	7	5	0	3	1	0	0	3	0	
MAY	70.3	48.1	59.2	83	24+	32	4	198	25	6.14	1.81	6	0.0	0.0		77	82	56	57	23	2.0	8.8	29	21	24		6.0	9	12	10	11	0	6	0	0	0	1	0	
JUN	84.2	63.2	73.7	93	27	53	10	0	266	7.84	3.08	21-22	0.0	0.0		86	87	62	67	21	2.3	6.7	21	29	30		6.2	6	14	10	11	0	9	1	2	0	0	0	
JUL	83.1	64.6	73.9	91	9	56	28+	0	281	7.64	2.38	18-19	0.0	0.0		83	85	61	68	21	2.1	7.0	24	02	18		6.3	6	14	11	17	0	12	0	2	0	0	0	
AUG	84.7	63.0	73.9	92	20	54	28	0	285	0.88	0.36	2-3	0.0	0.0		80	83	55	63	10	1.0	6.1	15	25	26+		5.5	9	10	12	5	0	2	2	3	0	0	0	
SEP	81.7	63.3	72.5	91	10+	50	22	8	239	3.51	1.95	25-26	0.0	0.0		84	85	61	71	16	1.3	6.6	22	18	20		7.2	5	9	16	10	0	6	1	7	0	0	0	
OCT	75.0	54.3	64.7	87	2	40	8	69	65	0.52	0.16	21	0.0	0.0		80	86	58	68	16	1.8	6.9	18	18	27+		5.5	13	5	13	5	0	1	8	0	0	0	0	
NOV	57.3	37.1	47.2	80	1	18	8	536	10	1.71	0.52	19	0.7	0.7	23-24	72	74	52	65	22	3.8	9.6	22	21	18		6.5	6	9	15	9	0	0	0	0	0	13	0	
DEC	54.5	36.8	45.7	72	10	15	18	591	0	4.30	1.53	5-6	T	T	17 +	74	77	62	68	20	4.1	10.9	37	19	10		7.8	4	6	21	10	0	1	3	0	0	12	0	
YEAR	65.8	45.4	55.6	93	JUN. 27	-2	FEB. 2+	4468	1171	44.67	3.08	JUN. 21-22	19.1	7.3	FEB. 8	76	80	57	64	22	2.5	8.9	37	19	DEC. 10		6.4	84	118	163	113	5	45	24	14	20	94	3	

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Daily minimum	Monthly	Extremes Ø – Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity – Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind & – Mean speed	Prevailing direction	Fastest mile – Speed	Direction	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max. – 90° and above ‡	32° and below	Min – 32° and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	8		8		(b)	(b)	27		27		27		27	27		27		8	8	8	8	25	17	10	10			27	27	27	27	27	27	27	27	8	8	8	8	
J	42.9	26.1	34.5	71	1967	-10	1966+	946	4.94	16.65	1950	0.95	1970	2.98	1951	5.7	21.1	1948	9.4	1966	74	78	66	68	11.8	S	39	25	1962		7.2	6	6	19	13	2	1	3	0	10	24	2	
F	45.0	26.5	35.8	69	1971	-6	1970	818	3.42	7.69	1955	0.71	1968	3.09	1962	5.0	16.4	1960	7.3	1971	73	77	62	64	11.8	SSW	46	32	1962		6.9	7	5	16	11	2	1	2	0	5	23	1	
M	53.2	33.2	43.2	81	1967	12	1970	685	4.75	10.06	1964	0.99	1966	3.85	1952	3.3	17.7	1960	9.5	1947	69	75	57	57	12.0	SSW	36	27	1962		6.9	6	7	18	13	1	3	1	0	1	17	0	
A	65.1	43.6	54.4	84	1970	22	1964	325	4.04	9.30	1970	0.79	1946	4.39	1948	0.2	2.9	1961	2.9	1961	68	74	54	55	11.5	SSW	46	32	1963		6.6	6	9	15	12	*	4	1	0	0	3	0	
M	75.5	53.4	64.5	90	1964	26	1966	105	3.85	6.94	1967	1.20	1965	2.87	1955	0.0	0.0		0.0		73	78	54	56	9.3	S	35	22	1965+		6.1	8	10	13	12	0	6	1	*	0	*	0	
J	84.5	62.6	73.6	97	1966	39	1966	0	4.72	11.69	1960	1.36	1966	5.88	1960	0.0	0.0		0.0		78	81	56	59	8.3	S	35	22	1968		5.8	8	12	10	11	0	9	1	5	0	0	0	
J	88.2	66.5	77.4	98	1966	50	1968	0	3.98	10.64	1958	1.83	1951	2.67	1958	0.0	0.0		0.0		81	84	57	62	7.5	SSW	37	29	1966		5.6	9	12	10	11	0	10	1	6	0	0	0	
A	86.7	65.2	76.0	98	1964	42	1965	0	3.21	5.96	1969	0.88	1971	3.56	1968	0.0	0.0		0.0		79	84	55	60	7.0	S	39	22	1964		5.1	11	12	8	9	0	6	2	6	0	0	0	
S	80.8	57.8	69.3	96	1964	35	1965	54	2.80	5.71	1970	0.24	1959	3.50	1964	0.0	0.0		0.0		80	85	56	64	8.1	S	29	22	1968		5.0	11	9	10	7	0	3	2	2	0	0	0	
O	69.2	46.9	58.1	87	1971	27	1965+	239	2.28	4.46	1962	0.33	1963	3.21	1962	T	0.1	1954	0.1	1954	74	80	53	61	8.7	S	32	26	1965		4.8	13	8	10	7	0	1	2	0	0	3	0	
N	54.0	35.3	44.7	80	1971	9	1964	609	3.29	6.87	1951	1.02	1965	2.58	1957	0.6	9.7	1950	7.5	1966	75	79	60	67	10.7	S	30	22	1968		6.4	8	7	15	10	1	1	2	0	1	12	0	
D	44.1	27.6	35.9	72	1971	-4	1963	902	3.45	7.30	1951	0.61	1965	2.97	1949	1.7	10.7	1967	7.8	1967	75	78	65	70	11.4	S	37	19	1971		7.0	6	7	18	11	1	*	2	0	4	20	0	
YR	65.8	45.4	55.6	98	JUL. 1966+	-10	JAN. 1966+	4683	44.73	16.65	JAN. 1950	0.24	SEP. 1959	5.88	JUN. 1960	16.5	21.1	JAN. 1948	9.5	MAR. 1947	75	79	58	62	9.8	S	46	32	APR. 1963+		6.1	99	104	162	128	6	47	19	19	22	100	3	

Ø For period December 1963 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 108 in July 1936; lowest temperature -21 in January 1963; minimum monthly precipitation .11 in October 1924; maximum precipitation in 24 hours 8.06 in August 1932; maximum snowfall 21.7 in January 1918; maximum snowfall in 24 hours 13.4 in January 1943.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: MINNEAPOLIS-ST.PAUL, MINNESOTA INTERNATIONAL AIRPORT Standard time used: CENTRAL Latitude: 44° 53' N Longitude: 93° 13' W Elevation (ground): 834 feet Year: 1971

Month	Temperature – Averages – Daily maximum	Daily minimum	Monthly	Extremes – Highest	Date	Lowest	Date	Degree days (Base 65°) – Heating	Cooling	Precipitation – Total	Greatest in 24 hrs	Date	Snow, Ice pellets – Total	Greatest in 24 hrs.	Date
JAN	14.7	-1.7	6.5	35	22+	-18	27	1811	0	1.22	0.24	25	19.9	3.9	25
FEB	25.0	9.0	17.0	42	17	-23	8	1341	0	1.74	0.59	26-27	13.9	5.4	4-5
MAR	35.2	20.8	28.0	67	31	3	3	1139	0	1.21	0.60	14-15	7.0	3.5	15
APR	58.9	35.0	47.0	79	20	17	3+	537	2	1.11	0.48	27-28	1.9	1.4	1-2
MAY	67.0	43.8	55.4	84	14	32	3	297	5	3.14	1.20	23-24	0.2	0.2	19
JUN	81.3	61.7	71.5	96	27	50	1	18	218	3.52	0.74	28-29	0.0	0.0	
JUL	79.8	57.8	68.8	90	21	47	29	16	141	3.94	2.39	7	0.0	0.0	
AUG	81.6	57.5	69.6	97	22	44	27	22	168	1.78	1.25	30-31	0.0	0.0	
SEP	73.3	52.3	62.8	94	2	34	23	164	106	2.73	0.92	29	0.0	0.0	
OCT	60.3	42.5	51.4	76	17	29	31	413	3	5.68	2.29	26-27	0.0	0.0	
NOV†	39.2	26.2	32.7	57	12	8	30	962	0	2.67	0.83	16-17	† 13.2	6.4	25-26
DEC	25.6	11.1	18.4	35	24+	-10	17	1438	0	0.70	0.33	27	12.8	6.0	27
YEAR	53.5	34.7	44.1	97	AUG. 22	-23	FEB. 8	8158	643	29.44	2.39	JUL. 7	68.9	6.4	NOV. 25-26

Month	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind & – Resultant – Direction	Speed	Average speed	Fastest mile – Speed	Direction #	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Maximum – 90° and above ‡	Maximum – 32° and below	Minimum – 32° and below	Minimum – 0° and below	Average daily solar radiation - langleys
JAN	64	66	60	60	31	4.8	11.1	37	NW	29	52	6.0	11	7	13	13	8	0	0	0	29	31	20	
FEB	72	73	65	64	32	3.0	10.9	42	NW	27	49	6.6	8	3	17	10	6	0	2	0	20	28	8	
MAR	72	73	63	62	32	2.4	10.5	32	NW	27	52	7.2	6	6	19	11	3	2	1	0	11	29	0	
APR	57	69	43	41	33	1.9	11.4	36	NW	1	70	6.0	8	10	12	11	1	1	0	0	1	9	0	
MAY	59	70	44	42	02	1.9	10.2	25	E	31+	69	5.4	11	6	14	8	0	6	0	0	0	1	0	
JUN	70	75	57	57	17	1.6	9.0	32	SE	04	67	6.6	6	11	13	11	0	9	1	2	0	0	0	
JUL	71	75	50	51	26	2.7	9.1	33	NE	7	80	5.5	9	13	9	8	0	5	0	1	0	0	0	
AUG	70	78	47	47	17	1.6	8.5	29	SE	31	78	4.5	13	12	6	5	0	5	0	4	0	0	0	
SEP	74	81	55	58	19	2.6	9.1	34	SW	30	64	5.7	11	8	11	10	0	6	1	3	0	0	0	
OCT	79	86	68	71	25	1.6	10.1	42	SW	30	47	7.2	4	8	19	13	0	3	2	0	0	3	0	
NOV†	81	83	69	71	27	2.0	10.7	34	NW	20	33	7.7	4	6	20	10	4	0	2	0	10	25	0	
DEC	78	80	75	76	23	1.9	9.2	32	NW	24	24	7.7	5	4	22	10	3	0	2	0	25	30	6	
YEAR	71	76	58	58	28	1.3	10.0	42	SW	OCT. 30+	60	6.3	96	94	175	120	25	37	11	10	96	156	34	

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

In the November issue, also correct Col. 11 to .1 on the 19th.

NORMALS, MEANS, AND EXTREMES

Month	Temperature – Normal – Daily maximum	Daily minimum	Monthly	Extremes – Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation – Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs	Year	Snow, Ice pellets – Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	12		12		(b)	(b)	33		33		33		33	33		33	
J	22.4	2.3	12.4	46	1961	-34	1970	1631	0.70	3.63	1967	0.11	1959	1.21	1967	8.5	35.3	1967	7.6	1950
F	26.3	5.0	15.7	54	1964	-28	1965	1380	0.78	2.07	1962	0.06	1964	1.10	1966	8.3	26.5	1962	9.3	1939
M	37.2	17.6	27.4	83	1968	-32	1962	1166	1.53	4.75	1965	0.32	1958	1.66	1965	10.6	40.0	1951	13.7	1952
A	55.7	32.8	44.3	91	1962	2	1962	621	1.85	4.07	1967	0.59	1952	1.57	1954	2.3	9.6	1957	9.3	1949
M	69.1	45.4	57.3	95	1969	18	1967	288	3.19	8.03	1962	0.61	1967	3.03	1965	0.2	3.0	1946	3.0	1946
J	78.1	55.5	66.8	99	1963	37	1969	81	4.00	7.80	1946	1.26	1950	2.53	1954	0.0	0.0		0.0	
J	83.9	60.7	72.3	99	1966	45	1967+	22	3.27	7.10	1955	0.96	1947	4.12	1949	0.0	0.0		0.0	
A	81.3	58.6	70.0	98	1964	39	1967	31	3.18	6.60	1959	0.43	1946	3.22	1956	0.0	0.0		0.0	
S	72.2	48.5	60.4	95	1960	27	1965+	189	2.43	7.53	1942	0.41	1940	3.55	1942	0.1	1.7	1942	1.7	1942
O	60.6	37.2	48.9	87	1969	16	1962	505	1.59	5.68	1971	0.01	1952	2.95	1966	0.3	3.7	1959	2.5	1955
N	40.5	21.8	31.2	69	1964	-17	1964	1014	1.40	5.15	1940	0.02	1939	2.91	1940	5.9	26.3	1940	16.2	1940
D	27.4	8.7	18.1	62	1962	-22	1967	1454	0.86	2.21	1968	T	1943	1.11	1953	8.7	33.2	1969	9.8	1945
YR	54.6	32.8	43.7	99	JUL. 1966+	-34	JAN. 1970	8382	24.78	8.03	MAY 1962	T	DEC. 1943	4.12	JUL. 1949	44.9	40.0	MAR. 1951	16.2	NOV. 1940

Month	Relative humidity – Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind & – Mean speed	Prevailing direction #	Fastest mile – Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days – Sunrise to sunset – Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures – Max. – 90° and above ‡	Max. – 32° and below	Min. – 32° and below	Min. – 0° and below	Average daily solar radiation - langleys
(a)	12	12	12	12	33	14	33	33		33	33	33	33	33	33	33	33	33	12	12	12	12	
J	73	74	68	68	10.5	NW	40	SE	1956+	50	6.4	8	7	16	9	3	*	1	0	25	31	15	
F	73	75	65	65	10.7	NW	52	NW	1952	57	6.1	8	7	13	7	2	*	1	0	19	28	9	
M	74	78	64	64	11.3	NW	47	E	1951	54	6.6	7	8	16	10	3	1	1	0	12	27	2	
A	70	77	55	54	12.5	NW	52	WSW	1964	56	6.5	7	8	15	10	1	2	1	*	*	13	0	
M	70	77	54	52	11.6	SE	61	NW	1964	58	6.4	7	9	15	12	*	5	1	1	0	2	0	
J	75	81	56	55	10.7	SE	63	NW	1939	62	6.1	7	11	12	12	0	8	1	3	0	0	0	
J	78	83	56	55	9.3	S	92	W	1951	70	5.1	11	11	9	10	0	7	*	6	0	0	0	
A	78	85	55	55	9.1	SE	63	N	1967	67	5.1	11	11	9	9	0	6	1	4	0	0	0	
S	82	88	61	63	10.0	S	47	N	1951	61	5.4	10	9	11	9	*	4	1	1	0	1	0	
O	76	84	59	64	10.5	SE	73	S	1949	57	5.5	11	7	13	8	*	2	1	0	0	7	0	
N	79	82	67	71	11.1	NW	60	SW	1958	39	7.1	5	7	18	8	2	1	1	0	5	22	*	
D	77	79	72	73	10.4	NW	52	W	1946	40	7.0	6	7	18	9	3	*	1	0	22	29	8	
YR	75	80	61	62	10.6	NW	92	W	JUL. 1951	58	6.1	98	102	165	113	14	36	11	14	83	159	35	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 108 in July 1936; maximum monthly precipitation 11.87 in July 1892; maximum precipitation in 24 hours 7.80 in July 1892.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

\# To 8 compass points only.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: PITTSBURGH, PENNSYLVANIA GREATER PITTSBURGH AIRPORT Standard time used: EASTERN Latitude: 40° 30' N Longitude: 80° 13' W Elevation (ground): 1137 feet Year: 1971

Month	Temperature: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days (Base 65°): Heating	Cooling	Precipitation: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date
JAN	31.4	15.9	23.7	55	4	-3	31	1277	0	2.29	0.99	4	12.1	2.8	31-1
FEB	37.5	23.3	30.4	62	26	-6	2	961	0	4.04	1.06	22	20.6	9.2	8-9
MAR	42.5	26.0	34.3	71	14	14	25	949	0	3.20	0.99	12-13	16.8	9.0	3-4
APR	57.9	34.1	46.0	79	13+	24	27+	562	0	0.48	0.17	17	0.2	0.2	5
MAY	68.0	45.2	56.6	84	19+	30	4	264	13	3.87	2.44	5-6	0.0	0.0	
JUN	82.3	60.4	71.4	96	28	49	10	6	204	1.41	0.47	13	0.0	0.0	
JUL	80.4	60.0	70.2	89	8	49	18	1	171	6.82	2.97	10-11	0.0	0.0	
AUG	80.5	58.7	69.6	87	21+	47	24	6	158	1.23	0.38	23	0.0	0.0	
SEP	77.4	59.5	68.5	91	9	41	25	41	153	3.86	0.80	25-26	0.0	0.0	
OCT	69.2	49.7	59.5	80	2	37	8	184	17	0.84	0.49	24	0.0	0.0	
NOV	48.3	32.5	40.4	72	15+	9	23	729	0	1.94	0.47	24	10.5	3.3	21-22+
DEC	46.9	30.6	38.8	72	10	14	3	807	0	3.24	1.47	5-6	0.7	0.7	17
YEAR	60.2	41.3	50.8	96	JUN. 28	-6	FEB. 2	5787	716	33.22	2.97	JUL. 10-11	60.9	9.2	FEB. 8-9

Month	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Resultant: Direction	Speed	Average speed	Fastest mile: Speed	Direction	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Maximum: 90° and above ‡	Maximum: 32° and below	Minimum: 32° and below	Minimum: 0° and below	Average daily solar radiation - langleys
JAN	75	76	70	71	27	7.6	11.9	48	27	30	26	8.2	4	3	24	20	6	1	3	0	13	28	3	
FEB	70	70	61	64	26	6.2	12.1	32	25	28	28	7.9	5	4	19	16	4	1	0	0	8	20	2	
MAR	71	74	59	62	28	6.7	12.4	46	27	16+	43	7.8	5	5	21	19	4	2	0	0	6	27	0	
APR	59	67	39	41	30	6.2	11.2	35	23	1	55	6.3	7	9	14	8	0	0	1	0	0	10	0	
MAY	68	74	48	50	30	3.7	9.1	25	23	25+	49	7.0	5	9	17	11	0	2	0	0	0	2	0	
JUN	75	78	53	58	26	2.5	7.0	22	30	6	55	6.6	2	17	11	7	0	9	3	3	0	0	0	
JUL	74	77	53	55	25	2.1	7.0	35	36	6	63	6.3	5	13	13	11	0	6	3	0	0	0	0	
AUG	81	85	54	60	27	2.4	6.7	21	30	11	67	5.4	12	5	14	11	0	5	2	0	0	0	0	
SEP	83	86	63	72	22	0.3	7.2	23	29	20	38	7.4	5	6	19	13	0	4	8	2	0	0	0	
OCT	85	88	61	71	18	0.9	7.6	25	26	11	58	5.7	10	8	13	8	0	1	1	0	0	0	0	
NOV	73	75	62	67	27	5.9	10.5	25	30	21+	44	7.8	4	6	20	12	3	0	3	0	3	15	0	
DEC	72	75	63	65	26	5.3	11.0	33	27	30	22	8.3	3	3	25	15	0	0	3	0	3	18	0	
YEAR	74	77	57	61	27	3.9	9.5	48	27	JAN. 30	48	7.1	67	88	210	151	17	31	27	5	33	120	5	

NORMALS, MEANS, AND EXTREMES

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	(b)	(b)	12		12		(b)	(b)	19		19		19	
J	36.5	21.2	28.9	66	1967	-18	1963	1119	2.97	4.52	1966	1.06	1967	1.42	1966
F	37.6	20.7	29.2	66	1961	-9	1963	1002	2.19	5.98	1956	0.51	1969	1.72	1966
M	46.1	27.4	36.8	80	1966	-1	1960	874	3.32	6.10	1967	1.14	1969	2.00	1964
A	60.0	37.9	49.0	87	1970	15	1964	480	3.08	7.61	1964	0.48	1971	2.15	1964
M	71.4	48.1	59.8	91	1962	26	1970+	195	3.91	6.36	1968	1.21	1965	2.44	1971
J	79.9	56.9	68.4	96	1971+	36	1966	39	3.78	4.61	1970	0.90	1967	1.93	1955
J	83.3	60.9	72.1	98	1966	42	1963	0	3.88	7.43	1958	1.82	1965	2.97	1971
A	81.9	59.6	70.8	95	1962+	40	1965	9	3.31	6.77	1955	0.78	1957	3.06	1956
S	75.5	52.8	64.2	95	1959	31	1959	105	2.54	4.69	1962	0.74	1964	2.10	1958
O	63.7	42.4	53.1	87	1959	16	1965	375	2.52	8.20	1954	0.16	1963	3.56	1954
N	49.5	32.0	40.8	82	1961	8	1959	726	2.24	3.41	1961	1.00	1954	1.38	1961+
D	38.1	23.2	30.7	72	1971	-5	1962	1063	2.40	4.26	1964	0.40	1955	1.47	1971
YR	60.3	40.3	50.3	98	JUL. 1966	-18	JAN. 1963	5987	36.14	8.20	OCT. 1954	0.16	OCT. 1963	3.56	OCT. 1954

Month	Snow, Ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max.: 90° and above ‡	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average daily solar radiation - langleys
(a)	19	19		19		12	12	12	12	19	11	19	19		19	19	19	19	19	19	19	19	19	12	12	12	12	
J	11.0	24.6	1966	14.0	1966	73	76	66	68	10.8	WSW	48	27	1971	37	8.0	3	6	22	16	3	*	2	0	15	27	3	
F	10.6	22.5	1961	12.3	1960	73	76	64	66	11.1	WSW	58	26	1967	39	7.9	3	6	19	14	3	*	1	0	11	25	2	
M	10.4	21.3	1960	14.7	1962	72	77	60	62	11.1	WSW	48	25	1954	47	7.6	4	7	20	16	3	2	1	0	5	21	*	
A	1.6	5.9	1961	3.9	1953	67	73	51	54	10.8	WSW	46	25	1970+	50	7.4	4	8	18	13	*	4	1	0	0	9	0	
M	0.3	3.1	1966	3.1	1966	73	76	51	55	9.4	WSW	42	25	1957	55	6.9	5	9	17	12	*	5	1	1	0	1	0	
J	0.0	0.0		0.0		78	79	52	57	8.1	WSW	40	27	1957	61	6.4	5	12	13	11	0	7	1	3	0	0	0	
J	0.0	0.0		0.0		80	83	52	59	7.5	WSW	51	25	1956	63	6.5	5	13	13	11	0	7	1	3	0	0	0	
A	0.0	0.0		0.0		82	86	55	62	7.3	WSW	46	29	1963+	63	6.1	6	13	12	9	0	6	2	1	0	0	0	
S	0.0	0.0		0.0		82	86	56	66	7.7	WSW	32	02	1960+	63	6.0	8	10	12	8	0	3	3	1	0	0	0	
O	0.2	1.8	1962	1.8	1962	75	81	52	61	8.5	WSW	35	27	1959+	58	6.0	9	8	14	10	*	2	2	0	0	4	0	
N	4.2	11.0	1958	10.5	1958	75	80	62	69	10.2	WSW	45	29	1969	41	7.7	4	6	20	13	1	*	2	0	2	14	0	
D	9.0	20.8	1960	6.9	1960	76	78	68	71	10.7	WSW	48	25	1968	32	8.2	3	6	22	16	3	*	2	0	12	25	1	
YR	47.3	24.6	JAN. 1966	14.7	MAR. 1962	76	79	57	62	9.4	WSW	58	26	FEB. 1967	52	7.1	59	104	202	150	14	35	18	8	44	126	5	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
AIRPORT - Highest temperature 102 in July 1936; maximum monthly precipitation 10.25 in June 1951; maximum monthly snowfall 32.3 in November 1950; and maximum snowfall in 24 hours 17.5 in November 1950.
CITY OFFICE - Highest temperature 103 in July 1936; lowest temperature -20 in February 1899; minimum monthly precipitation 0.06 in October 1874; maximum precipitation in 24 hours 4.08 in September 1876; and maximum monthly snowfall 36.3 in December 1890.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

METEOROLOGICAL DATA FOR THE CURRENT YEAR

Station: SALEM, OREGON MC NARY FIELD Standard time used: PACIFIC Latitude: 44° 55' N Longitude 123° 01' W Elevation (ground): 196 feet Year: 1971

Month	Temperature Averages Daily maximum	Temperature Averages Daily minimum	Temperature Averages Monthly	Temperature Extremes Highest	Date	Temperature Extremes Lowest	Date	Degree days (Base 65°) Heating	Degree days Cooling	Precipitation Total	Precipitation Greatest in 24 hrs.	Date	Snow, Ice pellets Total	Snow, Ice pellets Greatest in 24 hrs.	Date	Relative humidity Hour 04 (Local time)	Hour 10	Hour 16	Hour 22	Wind & Resultant Direction	Resultant Speed	Average speed	Fastest mile Speed	Fastest mile Direction	Date	Percent of possible sunshine	Average sky cover sunrise to sunset	Number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Maximum 90° and above ‡	Maximum 32° and below	Minimum 32° and below	Minimum 0° and below	Average daily solar radiation - langleys
JAN	44.7	33.4	39.1	64	30	16	5	796	0	6.49	1.04	14-15	11.1	5.9	13-14	84	83	79	84	19	8.1	9.7	32	18	15		9.3	0	3	28	22	3	0	7	0	0	14	0	
FEB	48.5	30.3	39.4	63	13+	15	28	710	0	4.34	0.74	3-4	8.1	3.5	27-28	84	82	68	82	20	5.5	7.6	26	20	26+		8.4	2	2	24	17	3	1	6	0	0	18	0	
MAR	50.9	32.9	41.9	62	19	12	1	706	0	6.93	1.03	11-12	1.4	1.4	4	81	74	62	77	20	6.3	9.9	40	19	26		8.1	2	5	24	20	1	0	0	0	0	14	0	
APR	59.0	35.2	47.1	75	5	27	1	528	0	4.05	2.22	8-9	T	7	10	82	66	53	74	22	3.2	7.3	23	19	10		7.9	4	4	22	13	0	1	1	0	0	8	0	
MAY	66.4	40.2	53.3	89	11	32	21+	355	0	1.89	0.58	25-26	T	T	16	84	67	54	76	27	2.8	6.8	28	21	15		6.8	6	6	19	10	0	0	0	0	0	2	0	
JUN	69.5	46.8	58.2	88	21	41	30+	201	5	2.47	1.33	24-25	0.0	0.0		90	64	52	80	25	1.9	5.4	25	25	22		7.8	2	9	19	12	0	0	0	0	0	0	0	
JUL	82.7	51.9	67.3	97	20	40	3	61	140	0.01	0.01	9	0.0	0.0		88	58	40	71	32	2.0	5.3	20	36	14		4.1	15	9	7	1	0	1	0	8	0	0	0	
AUG	84.2	54.0	69.1	101	11	45	23	18	152	1.49	1.17	30-31	0.0	0.0		89	60	40	72	28	1.7	5.8	21	20	30		4.0	16	7	8	6	0	0	0	6	0	0	0	
SEP	72.4	45.8	59.1	85	22+	36	30	169	2	3.98	1.41	1-2	0.0	0.0		89	61	47	78	19	0.5	7.5	24	21	1		4.5	16	5	9	10	0	0	0	0	0	0	0	
OCT	61.5	39.7	50.6	84	8	23	29	440	0	3.09	1.34	18-19	0.0	0.0		93	82	61	89	19	1.9	6.2	30	18	19		6.9	5	7	19	13	0	0	6	0	0	5	0	
NOV	51.5	37.5	44.5	58	3	24	6	607	0	6.27	1.18	25-26	0.0	0.0		93	89	79	92	19	5.4	7.7	29	18	13+		9.0	1	4	25	17	0	0	10	0	0	7	0	
DEC	44.7	34.2	39.5	54	5	22	28	784	0	8.18	1.17	11-12	2.2	1.6	28	91	88	85	89	19	8.0	10.9	35	18	11		9.1	2	0	29	23	1	0	2	0	0	10	0	
YEAR	61.3	40.2	50.8	101	AUG. 11	12	MAR. 1	5375	299	49.19	2.22	APR. 8-9	22.8	5.9	JAN. 13-14	87	73	60	80	21	3.3	7.5	40	19	MAR. 26		7.2	71	61	233	164	8	3	32	14	0	78	0	

NORMALS, MEANS, AND EXTREMES

Month	Temperature Normal Daily maximum	Normal Daily minimum	Normal Monthly	Extremes ∅ Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity Hour 04 (Local time)	Hour 10	Hour 16	Hour 22	Wind & Mean speed	Prevailing direction	Fastest mile Speed	Fastest mile Direction	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures Max 90° and above ‡	Max 32° and below	Min 32° and below	Min 0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	10		10		(b)	(b)	34		34		34		34	34		34		9	9	9	9	23	15	22	22			27	34	34	34	34	34	34	34	9	9	9	9	
J	45.5	31.5	38.5	64	1971	8	1969	822	6.70	15.40	1953	0.57	1949	2.91	1956	4.2	32.8	1950	10.8	1943	88	86	79	87	8.9	S	40	18	1966+		8.4	2	5	24	19	1	*	7	0	1	13	0	
F	50.3	33.5	41.9	72	1968	15	1971	647	5.31	12.31	1949	0.78	1964	3.16	1949	0.9	8.4	1962	5.4	1962	88	82	68	84	7.9	S	46	18	1958		8.1	3	5	20	16	*	*	4	0	0	13	0	
M	55.1	35.5	45.3	73	1969	12	1971	611	4.68	8.42	1938	0.67	1965	3.03	1943	0.9	10.9	1951	8.5	1960	86	74	60	81	8.3	S	40	19	1971		7.8	4	6	21	17	*	*	2	0	0	13	0	
A	62.5	39.6	51.1	84	1968	23	1968	417	2.33	5.18	1955	0.39	1939	2.22	1971	T	T	1971+	T	1971+	86	70	57	78	7.4	S	44	18	1962		7.3	4	8	18	14	0	*	1	0	0	7	0	
M	68.3	44.2	56.3	92	1963	30	1966	273	2.11	4.58	1942	0.18	1947	1.84	1963	T	T	1971+	T	1971+	87	66	52	77	6.7	S	28	21	1971		6.9	6	8	17	11	0	1	1	*	0	1	0	
J	73.4	47.8	60.6	100	1969+	35	1965	144	1.45	3.60	1947	0.01	1951	1.60	1950	0.0	0.0		0.0		88	63	50	76	6.5	S	25	25	1971+		6.5	7	8	15	8	0	1	*	2	0	0	0	
J	81.7	50.4	66.1	104	1965	37	1962	37	0.35	1.41	1947	0.00	1967+	0.87	1961	0.0	0.0		0.0		87	58	40	70	6.6	N	26	20	1957		4.0	15	9	7	3	0	1	*	6	0	0	0	
A	80.8	51.3	66.1	102	1967	38	1969+	31	0.45	4.17	1968	T	1970+	1.25	1943	0.0	0.0		0.0		87	59	40	72	6.4	NW	24	29	1969		4.6	14	9	8	4	0	1	*	6	0	0	0	
S	76.8	48.1	62.5	98	1967	28	1970+	111	1.38	3.98	1971	0.01	1942	1.86	1951	0.0	0.0		0.0		87	65	47	79	6.3	S	31	18	1969		5.1	11	9	10	7	0	1	2	2	0	*	0	
O	65.7	42.5	54.1	93	1970	23	1971	338	3.91	11.17	1947	0.83	1952	2.84	1955	T	T	1970	T	1970	91	79	62	87	6.5	S	58	18	1962		6.9	5	9	17	13	0	*	7	*	0	4	0	
N	53.8	36.6	45.2	72	1970+	17	1969	594	5.71	13.38	1942	0.84	1939	2.82	1950+	0.2	5.8	1955	4.0	1955	91	86	78	89	7.5	S	38	18	1951		8.1	3	5	22	18	*	*	7	0	*	7	0	
D	48.6	34.3	41.5	61	1969+	8	1968	729	7.37	12.40	1964	2.67	1944	2.72	1964	1.2	12.6	1968	6.7	1968	88	87	82	87	8.4	S	45	23	1953		8.8	2	3	26	20	*	*	8	0	1	11	0	
YR	63.9	41.3	52.4	104	JUL. 1965	8	JAN. 1969+	4754	41.75	15.40	JAN. 1953	0.00	JUL. 1967+	3.16	FEB. 1949	7.4	32.8	JAN. 1950	10.8	JAN. 1943	88	73	60	81	7.3	S	58	18	OCT. 1962		6.9	76	84	205	150	2	6	39	17	2	70	0	

∅ For period July 1962 through the current year.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 108 in July 1941; lowest temperature -10 in January 1950; maximum monthly precipitation 17.54 in December 1933; maximum precipitation in 24 hours 4.30 in December 1933; maximum snowfall in 24 hours 25.0 in February 1937.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological standard normals (1931-1960).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
Below zero temperatures are preceded by a minus sign.
The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.
‡ ≥ 70° at Alaskan stations.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "Ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

APPENDIX C

SPECIFICATION FOR HEAT PIPES FOR HIGHWAY PAVEMENT HEATING SYSTEMS

REVISIONS				
LTR	PAGE	DESCRIPTION	DATE	APPROVED

CONTRACT NO.	dynatherm CORPORATION	COCKEYSVILLE, MARYLAND 21030
M. F. Pravda 4/13/74 PREPARED BY DATE	TITLE SPECIFICATION FOR HEAT PIPES FOR HIGHWAY PAVEMENT HEATING SYSTEMS	
REVIEWED/APPROVED DATE		
APPROVED DATE		
APPROVED DATE		
	SIZE A	CODE IDENT NO. 34881	DRAWING NO. 018-1011
	SCALE:	SHEET 1 OF 12

FORM D-0103 REV A (211)

1.0 SCOPE

This specification establishes the requirements for the fabrication and quality control of heat pipes for highway pavement heating systems. These requirements evolved from a combination of development testing at the Fairbank Highway Research Station and the results of an independent and extensive qualification program conducted by the Dynatherm Corporation.

2.0 APPLICABLE DOCUMENTS

The following documents, with amendments and the latest revisions, form a part of this specification. In the event of conflicts between documents referred to herein and the contents of this specification, this specification will prevail.

2.1 Specifications

DTM-M-100	Dynatherm Quality Assurance Manual
ASTM-A-120	Black and Hot-dipped Zinc-coated Welded and Seamless Steel Pipe for Ordinary Uses
MIL-C-16173	Corrosion Preventive Compound, Cold Application
ASTM-A-108	Cold-finished Carbon Steel Bars and Shafting

2.2 Procedures

DTM-089-1026	Qualification Heat Pipe Cleaning Procedure
DTM-089-1027	Qualification Heat Pipe Charging Procedure
DTM-001-1005	Emergency Procedure for Ammonia
GSFC-EX-D0109-C	Processing and Leak Checking Heat Pipes Containing Ammonia
MIL-C-45662A	Calibration System Requirements
MIL-T-5021	Test: Aircraft Welding Operator's Certification

3.0 REQUIREMENTS

3.1 Item Definition

In the context of this specification, the heat pipe consists of a straight sealed tubular pressure vessel containing a working fluid. The construction contractor will install the heat pipes in bored holes in the earth. The top portion of the heat pipes will be bent in the 3/4 inch section so that they lie within two inches and parallel to the finished pavement surface. The specifications for bending and installing the heat pipes will be provided by the State Highway Department. Adequate precautions, as defined in DTM-001-1005, shall be observed during site bending and installation of the heat pipes.

The basic heat pipe can be divided into three thermally distinctive sections. The evaporator section is that part which is located inside the bored hole. The adiabatic section comprises a segment between the bored hole and the pavement which is not used for heat transfer to the pavement. The condenser section is the remaining part outside the bored hole and within the concrete pavement.

3.2 Design and Physical Characteristics

3.2.1 Physical Description

The heat pipes are completely defined by this specification. The evaporator nominal diameter is 1.315 inch and has a tube wall thickness of 0.133 inch (Nominal one-inch pipe). The adiabatic and condenser sections shall have a nominal 1.050 inch diameter and a wall thickness of 0.113 inch (Nominal 3/4-inch pipe). The length of the evaporator, the length of the adiabatic/condenser, and the total length of the heat pipe shall be specified by the State Highway Department. The total length of heat pipes covered by this

specification shall not exceed 75 feet.

3.2.2 Installation

The heat pipes are to be installed into bored holes by the construction contractor at the construction site. The space around the heat pipes in the bored holes shall be filled (from the bottom up) by a slurry mixture of the material bored out of the hole.

3.2.3 Interchangeability

Heat pipes having the same part number shall be interchangeable with regard to form, fit, and function.

3.2.4 Maintainability

The heat pipes shall not require maintenance.

3.2.5 Operational Life

The heat pipes shall meet the performance requirements specified herein for a minimum service life of 20 years following exposure to the specified environments during handling, shipping, storing, and installation.

3.3 Performance

3.3.1 Functional Performance

3.3.1.1 Axial Heat Transport Capability

The heat pipes shall be capable of transporting a heat load corresponding to 6 watts per foot of evaporator length when the evaporator is installed vertically (to within $\pm$ 5 degrees) in the ground and the condenser is installed horizontally to within a tolerance of +20 and +1/4 degrees. Note that the permissible deviation from the

horizontal must be in such a direction that the working fluid can return by gravity to the evaporator.

3.3.1.2 Conductance

The maximum temperature difference between the outer wall of the evaporator and the outer wall of the condenser shall not exceed $3^{O}F$ for the heat load specified in 3.3.1.1. This requirement applies for any point in the evaporator but excluding the bottom most two feet of length. In the condenser, it applies to any part on the upper half of the heat pipe's circumference but excluding one foot of length at the end.

3.3.1.3 Temperature Range

The heat pipes shall meet the performance specified in 3.3.1.1 and 3.3.1.2 over the temperature range from $+20^{O}F$ to a maximum of $\div 75^{O}F$.

3.3.2 Environment

The heat pipes shall be capable of meeting the performance requirements specified herein during the natural operating environment and after being exposed to the nonoperating envoronment during handling, storage, shipping, and installation.

3.3.2.1 Natural Environment

After installation, the heat pipes will be exposed to ambient temperatures from $-30^{O}F$ to $+120^{O}F$. The evaporator sections will be in direct contact with the soil (temperature between $+30^{O}F$

and 60°F). The condenser/pavement section will be exposed to natural weather conditions (temperatures between -30°F and a maximum of 120°F).

3.3.2.2 Nonoperating Environment

The heat pipes shall be capable of withstanding storage under natural weather conditions for a period of two years while exposed to temperatures ranging from -30°F to +125°F. The heat pipes in their shipping configuration shall withstand shipment by truck, rail, or sea without affecting further performance.

3.4 Materials, Parts, and Processes

3.4.1 Heat Pipe Material

The basic heat pipe material shall be carbon steel pipe per ASTM-A-120 and shall be so certified.

3.4.2 End Cap, Fill Tube, and Protective Cap

End caps, fill tubes, and protective caps shall be fabricated from steel bar per ASTM-A-108.

3.4.3 Working Fluid

The working fluid shall be anhydrous ammonia with a minimum certified purity of 99.99%.

3.4.4 Processing - General

Processing of all parts, subassemblies, and assemblies shall be in accordance with applicable drawings and specifications. The major processes (and their sequence) specified in this plan are shown in Table 1.

TABLE 1

HEAT PIPE PROCESSING STEPS

(1) Raw Material Acquisition, Receiving Inspection, and Stocking

(2) Fabrication of Heat Pipe Components:

- Upper Tube Assembly
- End Caps
- Protective Cap
- Lower Tube Sections

(3) Clean All Heat Pipe Details

(4) Weld End Cap/Fill Tube on Upper Tube

(5) Join Lower Pipe Sections

(6) Weld Lower End Cap

(7) Join by Welding - Upper and Lower Subassemblies

(8) Evacuate and Charge

(9) Reflux and Outgas

(10) Pinch-Off and Seal Weld

(11) Leak Test Entire Assembly

(12) Install Steel Protective Cap over Fill Tube

(13) Stencil Mark Assembly

(14) Apply Light Oiling to Entire Assembly

(15) Bundle in groups of Nine for Shipment

(16) Store for Shipment

3.4.4.1 Cleaning

All heat pipe parts which will be in contact with ammonia and all weld joint areas shall be cleaned in accordance with a detailed production cleaning procedure. This procedure shall be in accordance with the basic process defined in Specification 089-1026.

3.4.4.2 Welding

All welding operations shall be performed by operators who have been certified to the requirements of MIL-T-5021 and who have been specifically qualified to perform the welds required for the heat pipes herein.

3.4.4.3 Charging and Outgassing

Charging of the heat pipe with working fluid and removal of noncondensing gases shall be performed per Specification 089-1027. The equipment defined in this specification may be modified; however, the basic process parameters such as cycle times, temperature, and pressures will not be altered.

3.4.4.4 Pinch-Off and Seal Weld

Absolute closure of the heat pipe shall be achieved by seal welding the pinch-off region of the fill tube in addition to the cold weld achieved during pinch-off. The pinch-off and seal welding will be done by a qualified process.

3.4.4.5 Marking

All heat pipes shall be stencil marked and the identification shall include as a minimum the manufacturer's name, part number,

serial number, and date of manufacture.

3.4.4.6 Protective Coating

A corrosion protection system shall be applied to the entire exterior of the heat pipe to minimize rusting during shipment. A cold applied solvent-cutback corrosion-preventive compound in accordance with MIL-C-16173D shall be employed.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General

Quality Assurance inspections and tests shall be performed in accordance with DTM-M-100, Dynatherm Quality Assurance Manual. Test equipment used to inspect and/or provide quantitative data shall be calibrated and maintained in calibration in accordance with MIL-C-45662A.

4.2 Inspection Records

An inspection log shall accompany each lot of heat pipes throughout the fabrication cycle (see DTM-089-1025). The chemical composition and, where applicable, material properties of all materials used in the processing and manufacturing cycle of each heat pipe lot shall be traceable. Nonconforming heat pipes will be properly tagged and segregated from normal production pipes.

4.3 Material Certification

Purchased raw materials used in the processing and manufacture of these heat pipes shall be accompanied, where available, by vendors' chemical and/or physical material certifications.

4.4 Inspections

Sufficient inspections shall be performed to ensure that all parts and assemblies conform to all applicable drawings and this specification with respect to all details including workmanship, processing, finish, construction, and identification.

4.5 Process Control

4.5.1 Chemical Analysis

Chemical analysis shall be performed on material lots. This applies to the pipe, end cap, and fill tube material, and the working fluid. This requirement is in addition to any material certifications supplied by the vendors.

4.5.2 Control of Cleaning Process

Quality Assurance shall ensure conformance to the requirements of this specification. Solvent control and product inspection after cleaning shall be specified and performed by Quality.

4.6 Acceptance Testing

All heat pipes shall be subjected to the following acceptance tests.

4.6.1 Determination of Adequate Amount of Working Fluid

The nominal amount of working fluid with which each heat pipe is charged has been determined based on the criteria that liquid and vapor phase are present at the refluxing (bleeding) temperature of $100 \pm 5^{\circ}F$. The presence of liquid at this temperature shall constitute an acceptance criterion. An insufficient amount of working fluid is indicated by a temperature excursion at the lower end of the heat pipe during refluxing or by an internal pressure less than the ammonia vapor pressure which would exist at a temperature corresponding to the lower end of the heat pipe. The test procedure shall specify

details of the measurement technique to be employed.

4.6.2 Leak Testing

All welds which seal the pressure vessel shall be leak tested after charging and pinch-off. The procedure shall specify a suitable technique, such as NASA-GSFC Procedure GSFC-EX-D-0109-C, which permits detection of ammonia leaking through a weld from a pressurized container.

4.6.3 Acceptance Criteria

A heat pipe lot shall be accepted for delivery at the plant of the manufacturer when:

- The pipes conform to all drawings and specifications.
- The pipes are charged with an adequate amount of working fluid (Section 4.6.1)
- The combined leak rate from all welds on each pipe will not cause more than 10% loss of working fluid over a period of 20 years (Section 4.6.2).
- The combined amount of noncondensing gases will not impair functional performance as defined in Section 3.3.
- The inspection log is complete and authenticated (Section 4.2).

4.7 Sampling Tests

The following tests shall be performed on randomly selected heat pipes.

4.7.1 Weld Integrity Tests

One heat pipe from each daily production shall be subjected to weld integrity tests. These will consists of dye penetrant checking of each seal weld. Dye penetrant testing of final pinch-off weld will also be performed.

4.7.2 Failure of Sampling Tests

If a heat pipe fails the weld integrity test, the particular welder

(operator) and welding machine shall be requalified before additional heat pipes are produced by that part of the production operation.

5.0 PREPARATION FOR DELIVERY

5.1 Handling

Materials shall be protected during all phases of fabrication, processing, and storage to prevent handling damage and foreign material contamination.

5.2 Storage

Materials to be stored shall be protected against deterioration and damage. Procedures shall be prepared and implemented which ensure the positive identification of materials.

5.3 Packaging

Packaging procedures and instructions shall be utilized and provided in order to protect materials while at the supplier's plant, during transportation to destination, and upon arrival at destination.

5.4 Marking

All markings on shipping containers shall be clearly legible from a distance of 36 inches and may be applied by stencil, rubber stamp. or lacquer. Markings shall be weatherproof.

FHWA
R&D